Emittance measurements and simulations at PITZ

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Photo Injector Test facility at DESY in Zeuthen

The Photo Injector Test facility at DESY in Zeuthen (PITZ) focuses on the development, test and optimization of high brightness electron sources for superconducting linac driven FELs:

⇒ test-bed for FEL injectors: FLASH, the European XFEL

⇒ **small transverse emittance (~1 mm mrad @ 1 nC)**

⇒ stable production of short bunches with small energy spread

⇒ further studies: dark current, QE, thermal emittance, …

+ detailed comparison with simulations = benchmarking for the PI physics

extensive R&D on photo injectors in parallel to FLASH operation

test and optimize rf guns for subsequent operation at the FLASH and XFEL

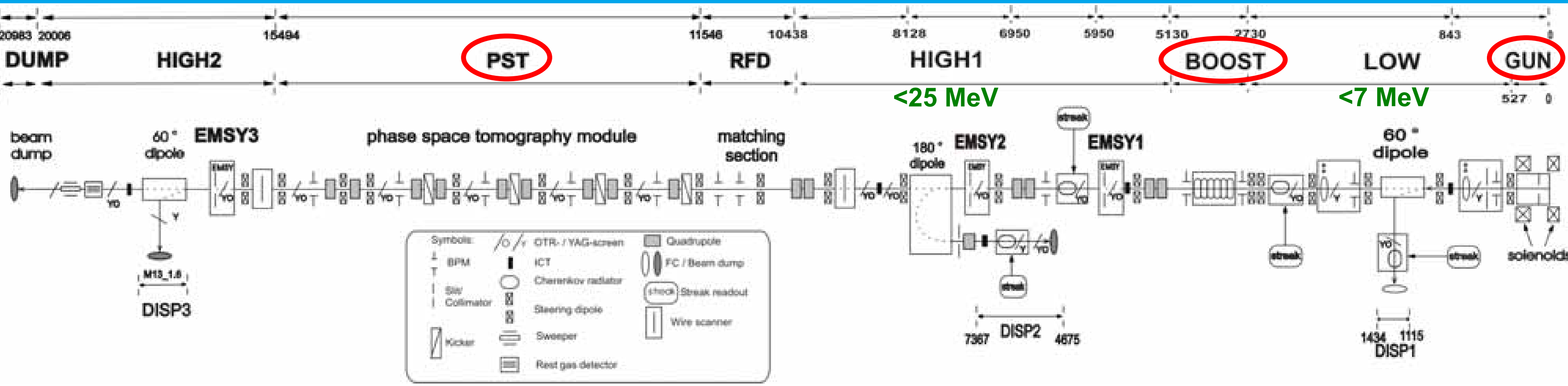
test new developments (laser, cathodes, beam diagnostics)

XFEL Photo Injector Key Parameters to be tested at PITZ

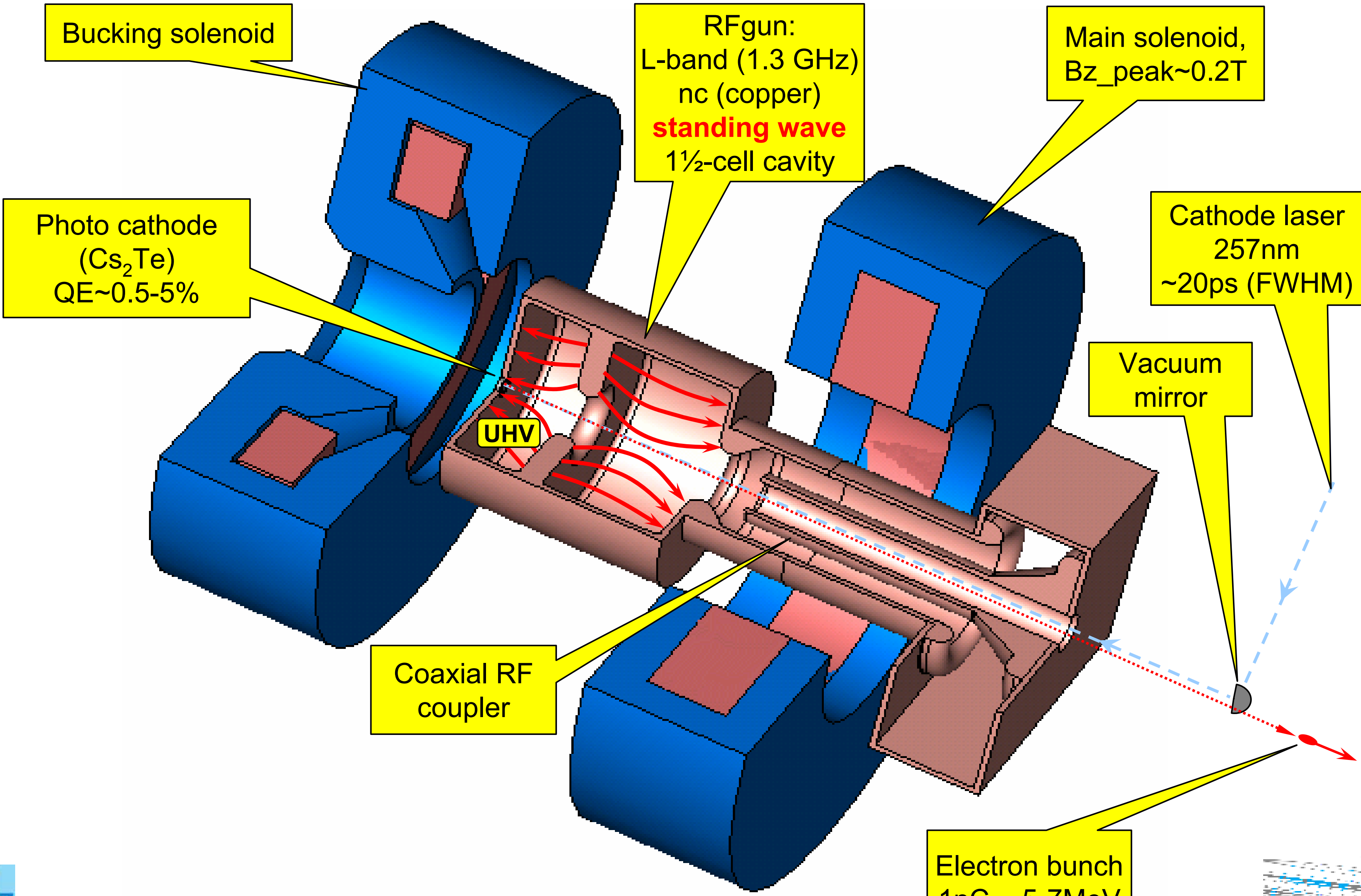
subsystem	parameter	*value*	remarks
RF gun cavity	frequency	*1.3 GHz*	
	E-field at cathode	***60 MV/m***	dark current issue
	RF pulse duration	*700 us*	max
	Repetition rate	*10 Hz*	max
Cathode laser	Temporal –> flat top –> FWHM	***20 ps***	**challenge** 20ps
	Temporal –> flat top –> rise/fal time	***2 ps***	
	Transverse – rad.homogen.XYrms	*0.3-0.4 mm*	fine tuning -> **thermal emittance**
	Pulse train length	*650 us*	max
	Bunch spacing	*222 ns (4.5MHz)*	1us (1MHz) at PITZ now
	Repetition rate	*10 Hz*	max
Electron beam	Bunch charge	*1 nC*	other charges under consideration
	Projected emittance at injector	***0.9 mm mrad***	
	Bunch peak current	*5 kA*	after bunch compression (not at PITZ)
	Emittance (slice) at undulator	***1.4 mm mrad***	

Main efforts at PITZ towards XFEL photoinjector

PITZ-1.8 setup



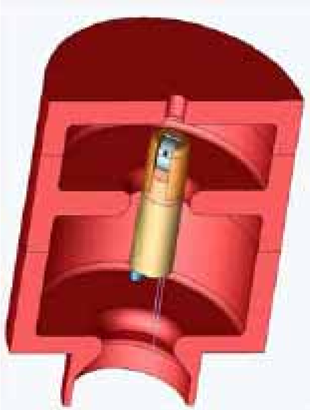
PITZ RF-Gun


Bucking solenoid
RFgun:
L-band (1.3 GHz)
nc (copper)
standing wave
1½-cell cavity
Main solenoid,
Bz_peak~0.2T
Photo cathode
(Cs_2Te)
QE~0.5-5%
Cathode laser
257nm
~20ps (FWHM)
Vacuum
mirror
UHV
Coaxial RF
coupler
Electron bunch
1nC, ~5-7MeV

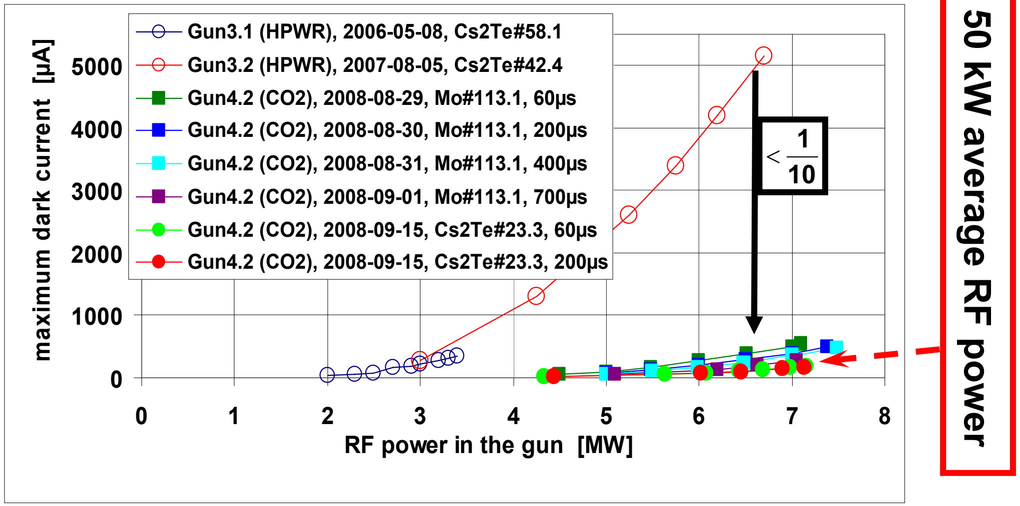
PITZ-1.7: New Gun-4.2

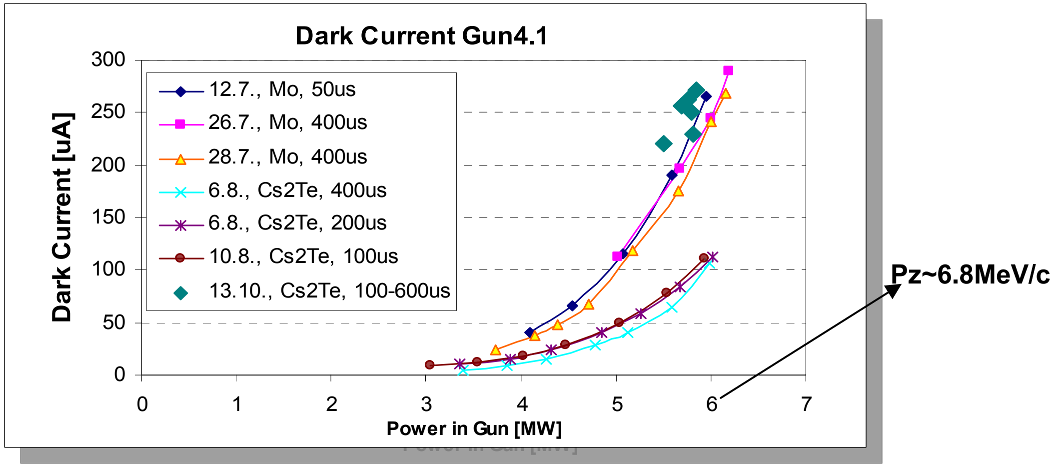
Dry-ice sublimation-impulse cleaning → **significant dark current reduction**

Vertical cleaning setup with 110º rotating nozzle.



Dark current measurements



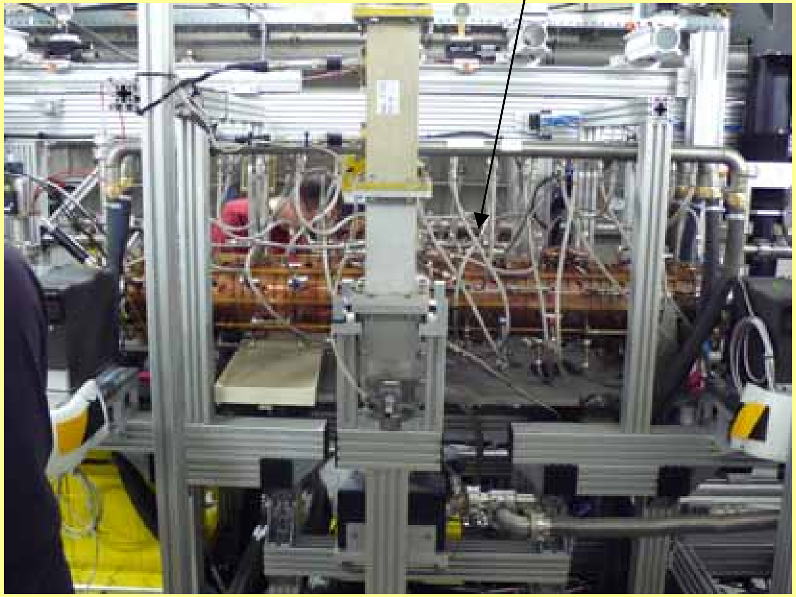


allows high brightness, high average current operation: 1–5 mA in 700 µs, 7–35 µA long term average

CDS-booster

Old **TESLA**-booster has been replaced with a specilly designed for PITZ **CDS**-booster

•restricted peak gradient (final beam momentun ~13MeV/c)
•short RF pulses only (50-100us)



CDS = Cut-Disc-Structure

•improved water cooling system
•higher peak gradients (final beam momentum ~25MeV/c
•long RF pulses (up to 700us)
•longer acceleration (L~1.4m)
•precise phase and amplitude control (RF probes)

Booster schematic cavity layout.
1 - regular cells,
2 - rf coupler, 3 - rf flanges,
5, 5a - photo multipliers,
6, 6a- vacuum gauges,
7 - pumping ports,
8 - ion pumps,
9 - internal cooling circuit,
10 - outer cooling circuit,
11 - support and adjustment.

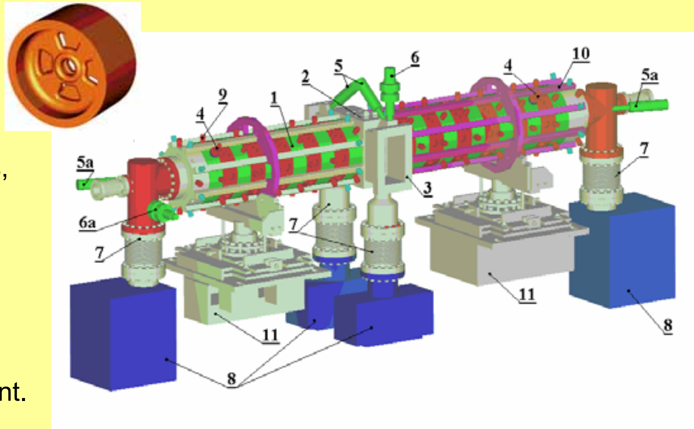


Photo cathode laser (Max-Born-Institute, Berlin)

Yb:YAG laser at PITZ with integrated optical sampling system

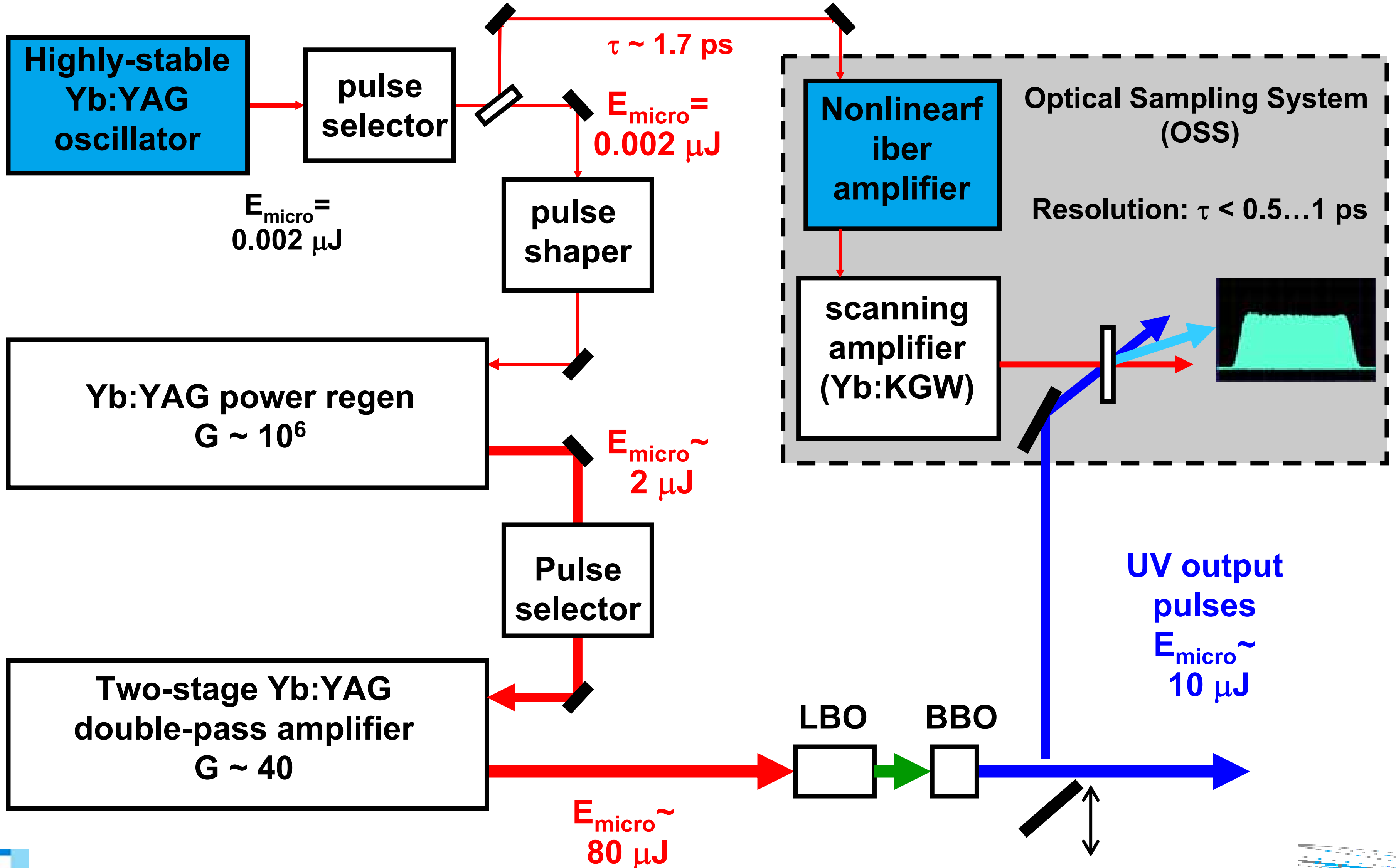
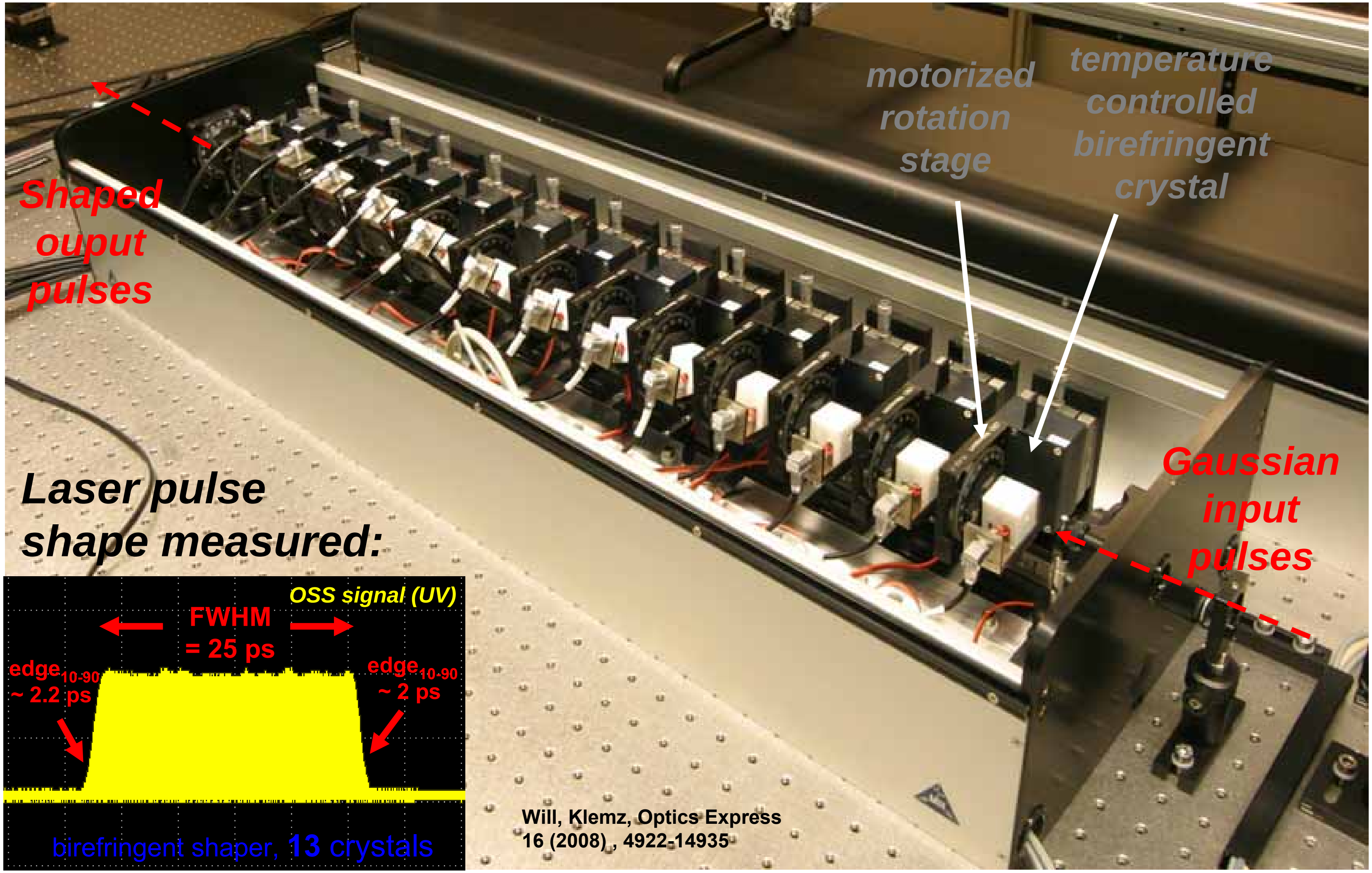
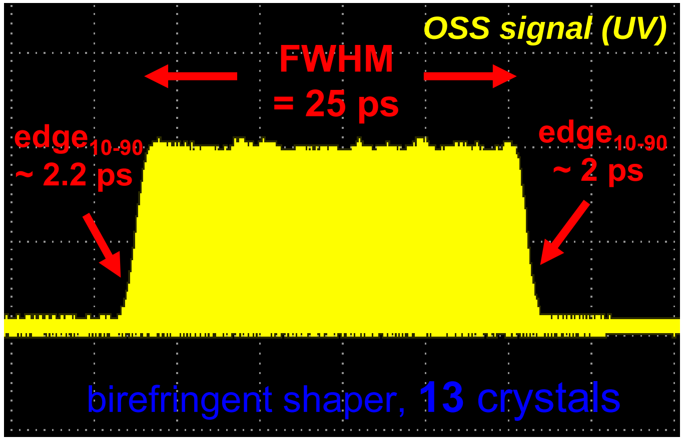


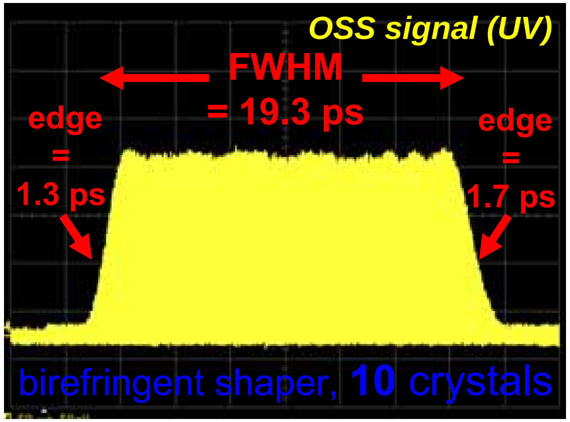
Photo cathode laser: temporal pulse shaping

Multicrystal birefringent pulse shaper containing 13 crystals

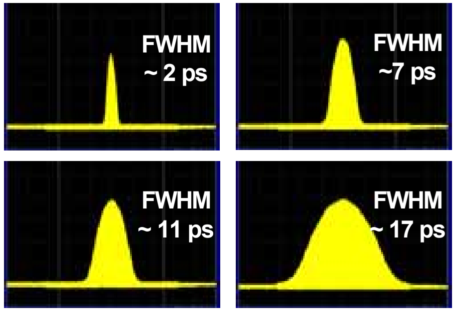


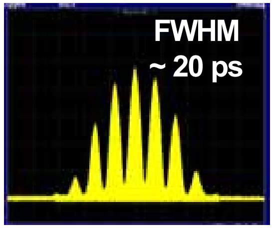
UV pulses of different shapes can be produced at the PITZ photo cathode



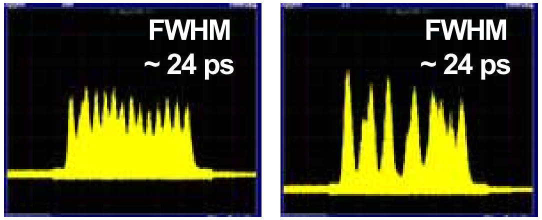


Gaussian:



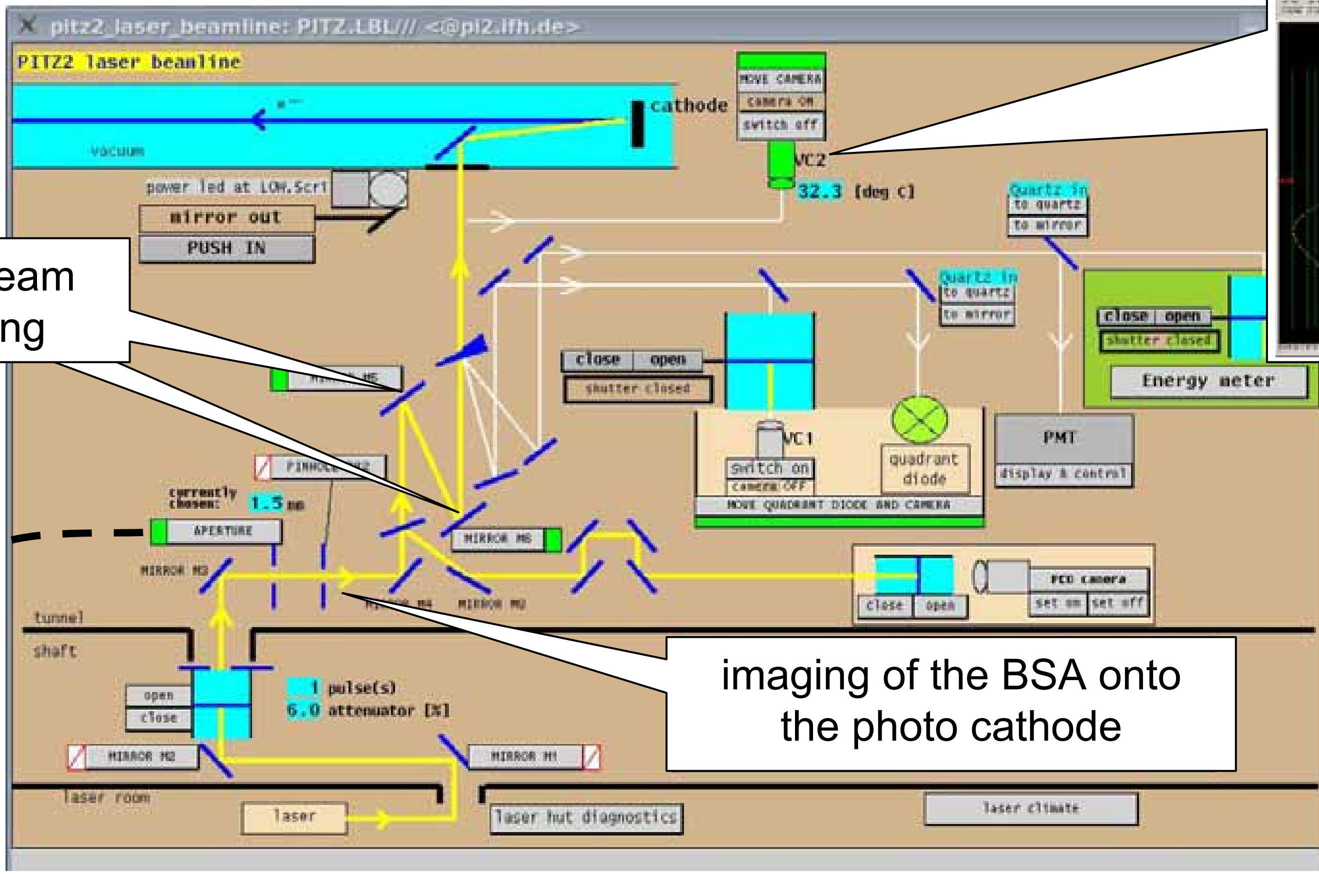


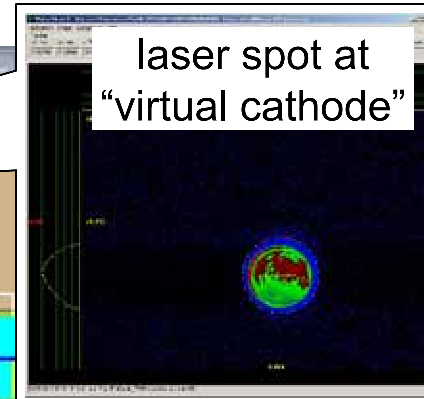
Simulated pulse-stacker



→ **High flexibility of photo cathode laser system**

Photo cathode laser: transverse pulse shaping

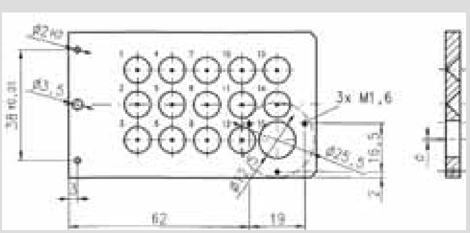




laser spot at “virtual cathode”

laser beam steering

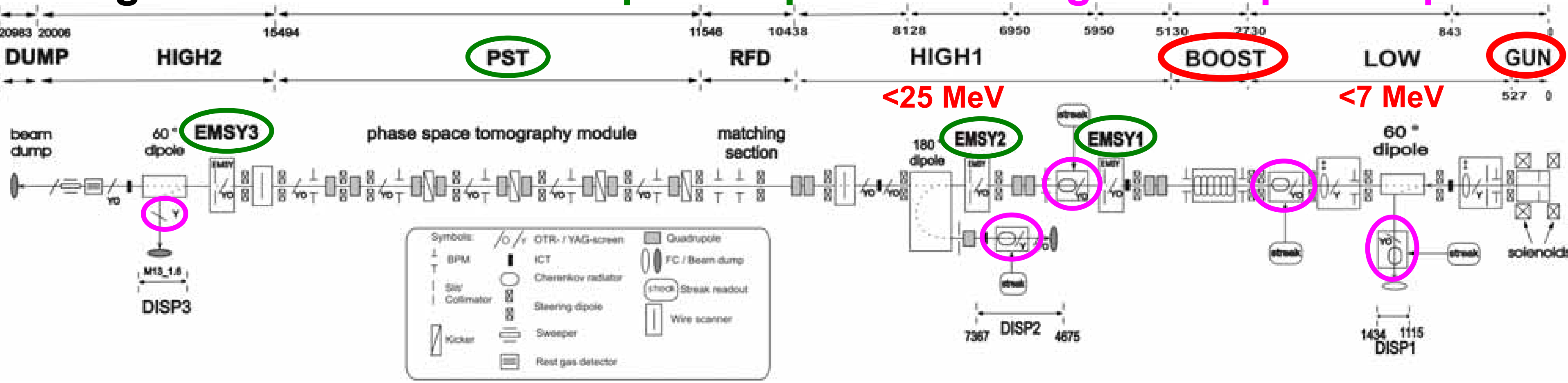
imaging of the BSA onto the photo cathode



Beam Shaping Aperture (BSA) plate is now replaced by an iris with remotely tunable opening

Beam diagnostics at PITZ

Diagnostics for Transverse phase space and Longitudinal phase space



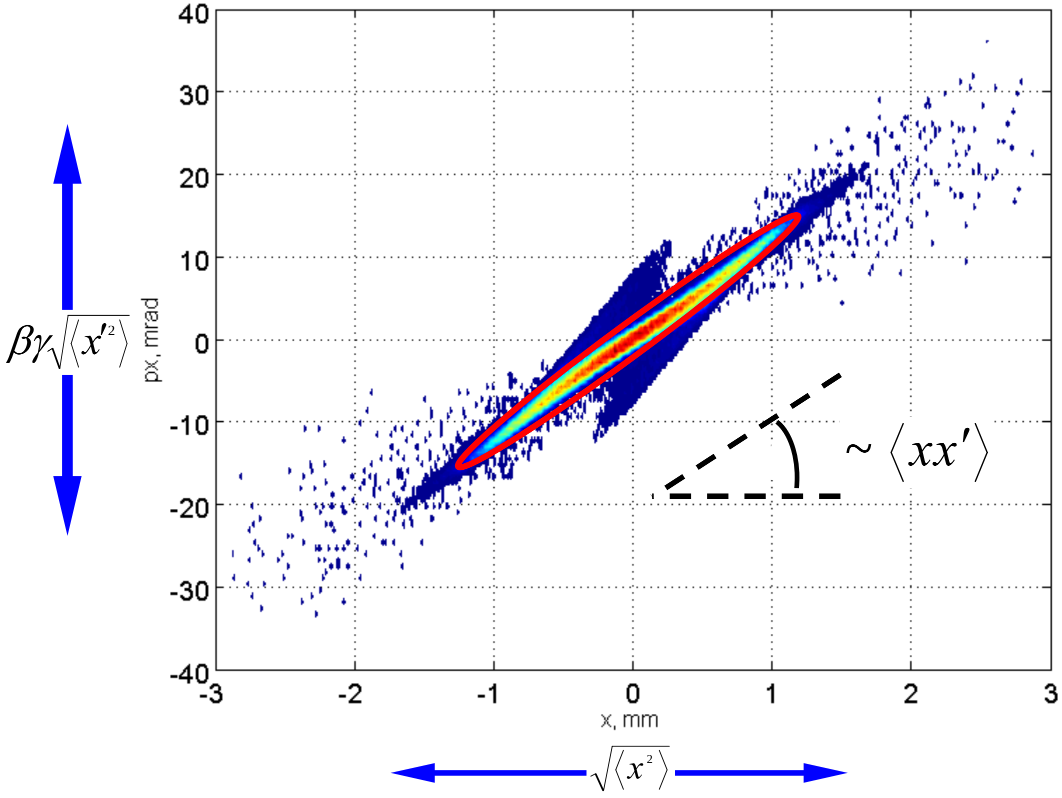
Component	Property	Diagnostics
Cathode laser	temporal profile	OSS, streak-camera
	transverse distribution	Virtual cathodes, CCD cameras
	pulse energy	Energy-meter, PMT
	position stability	Quadrant-diode
Electron beam	bunch charge	Faraday cups, Integrating current transformers
	beam position	BPMs
	longitudinal momentum	Dipoles+ dispersive arms (LEDA, HEDA1,2)
	transverse distribution	YAD and OTR screens with CCD cameras
	transverse phase space (emittance)	**Slit masks (EMSY1,2,3), quadrupoles, tomography module**
	longitudinal profile	Radiators (straight section) + streak read-out, upcoming – Transverse Deflecting Cavity
	longitudinal phase space	Radiators (dispersive arms) + streak read-out, upcoming – Transverse Deflecting System (TDS)+HEDA2 (slice energy spread)
	slice emittance	HEDA with booster off-crest, upcoming →TDS+HEDA2

Transverse Beam Emittance

PDF $f_6(x, p_x, y, p_y, z, p_z)$ → $f_2(x, p_x \propto \beta\gamma x')$

Normalized transverse emittance

$$\varepsilon_{nx} = \sqrt{\langle x^2\rangle\langle p_x^2\rangle - \langle x p_x\rangle^2} \rightarrow \varepsilon_{nx} = \beta\gamma\sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$$

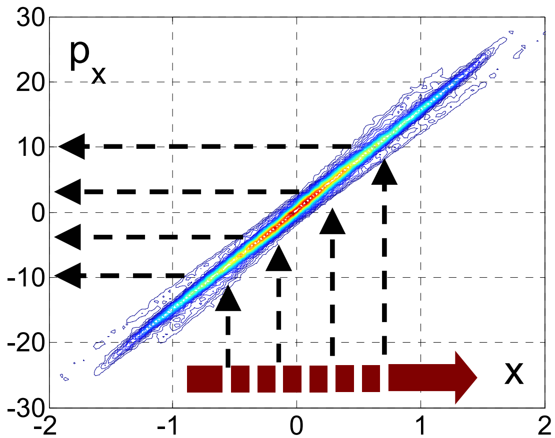


Transverse emittance measurements at PITZ

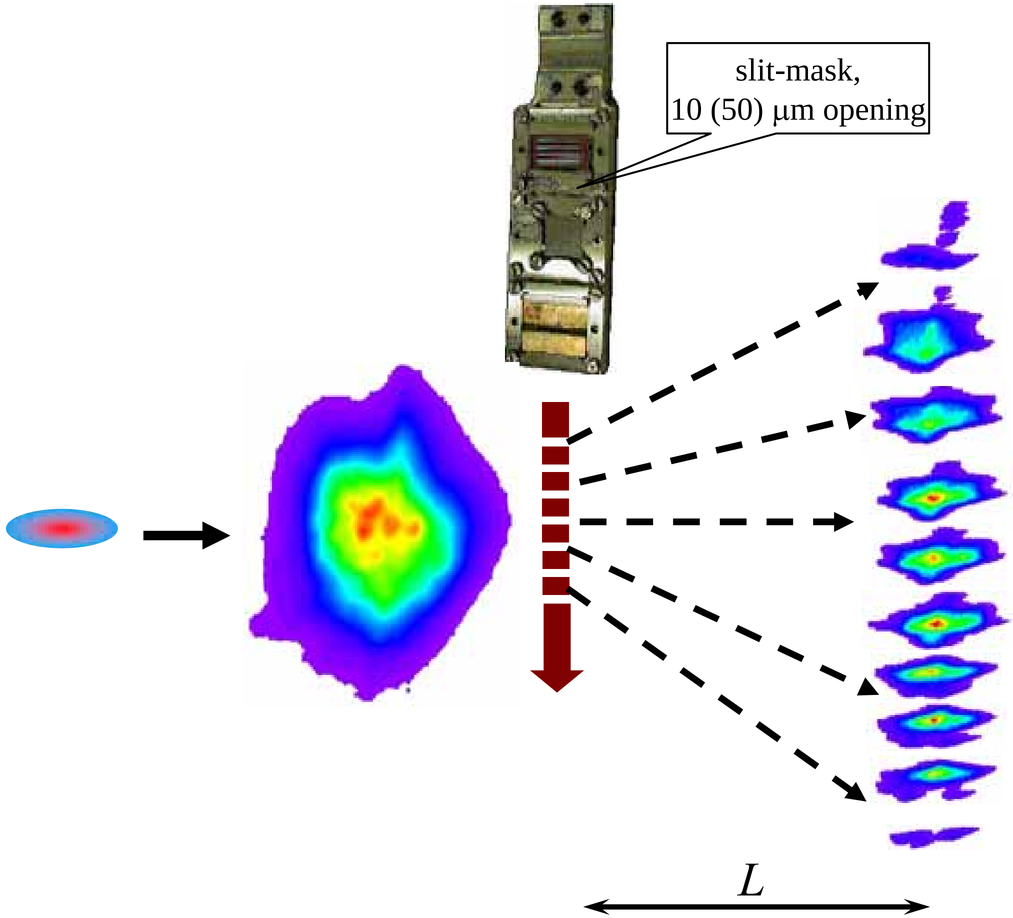
- Slit method
- Quad(s) scan
- Transverse phase space tomography
- Slice emittance:
  - Booster off-crest → HEDA
  - Upcoming TDS

Slit scan technique at PITZ

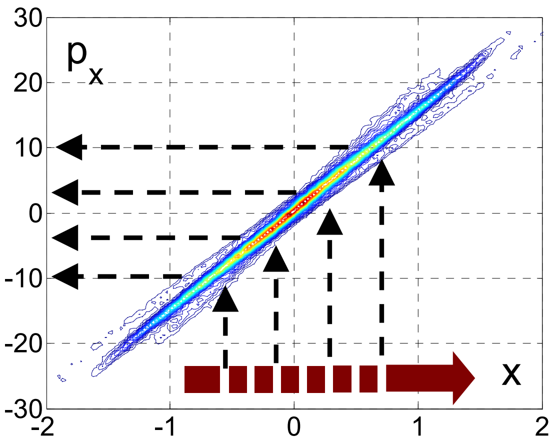
EMSY=Emittance Measurement SYstem



Transverse phase space reconstruction

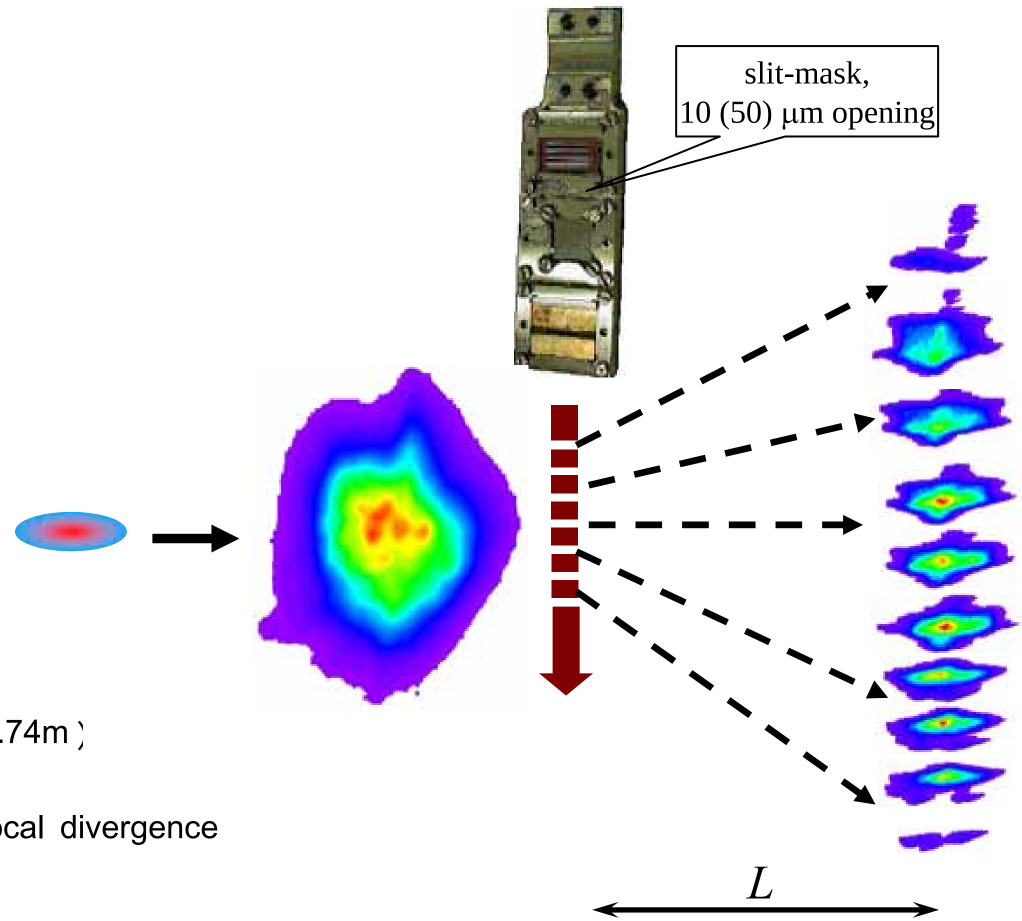


Slit scan technique at PITZ: sheared emittance



Transverse phase space reconstruction

EMSY=Emittance Measurement SYstem



$$\varepsilon_{x,n}^{sheared} = \beta\gamma \cdot X_{rms} \cdot X'_{rms}$$

X_{rms} - RMS size of full beam at EMSY station (e.g. z = 5.74m)

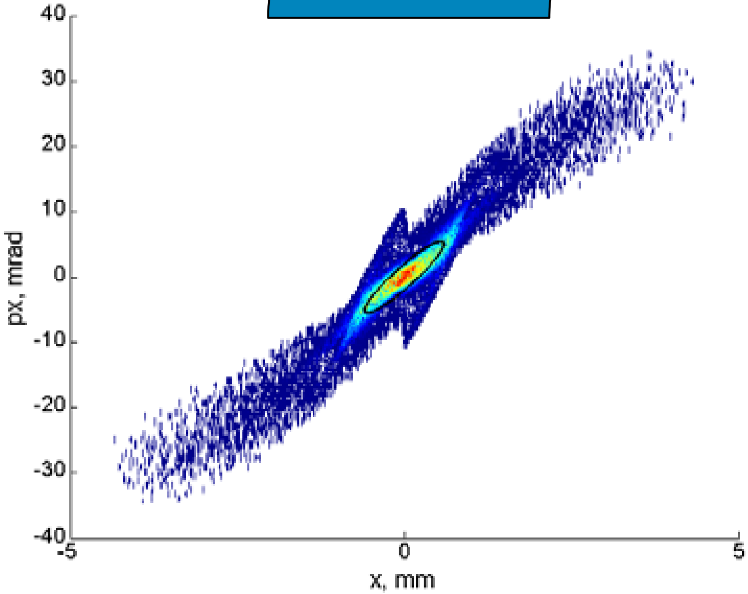
$$X'_{rms} = \frac{1}{L}\sqrt{\sum_{i=1}^{n} w_i \cdot \left(X_{rms}^{beamlet}\right)_i^2 \Big/ \sum_{i=1}^{n} w_i}$$ - uncorrelated local divergence

$X_{rms}^{beamlet}$ - RMS size of the beamlet image

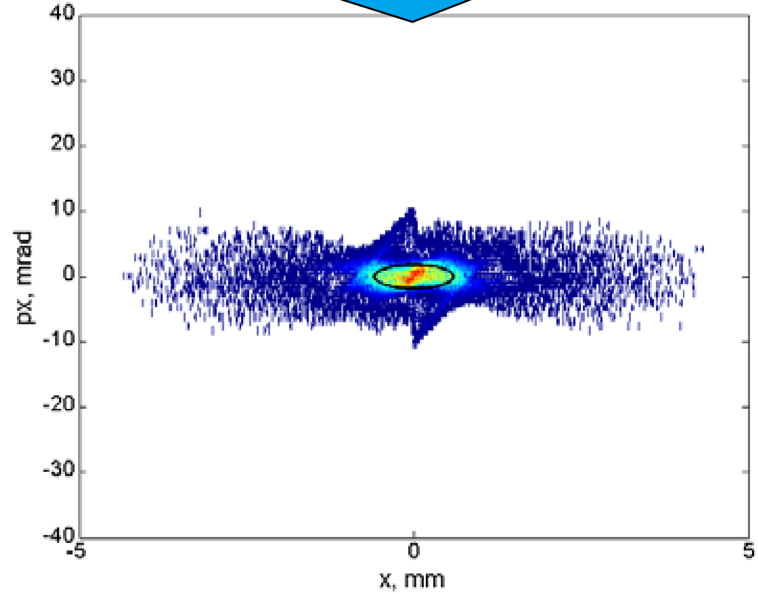
L - distance from slit location to the beamlet collector screen

Transverse phase space. Removing correlations

$$\sigma_{X'} = \frac{1}{L}\sqrt{\sum_{n=1}^{Nsl} w_n \cdot \left(\sigma_{X,n}^{BL}\right)^2 \Big/ \sum_{n=1}^{Nsl} w_n}$$



$$\varepsilon_{x,n} = 1.16\,\text{mm mrad}$$



$$\varepsilon_{x,n}^{sheared} = 1.03\,\text{mm mrad}$$

Phase space (nonlinear) correlations should be taken into consideration for the emittance calculations!

Slit scan technique at PITZ: evolution

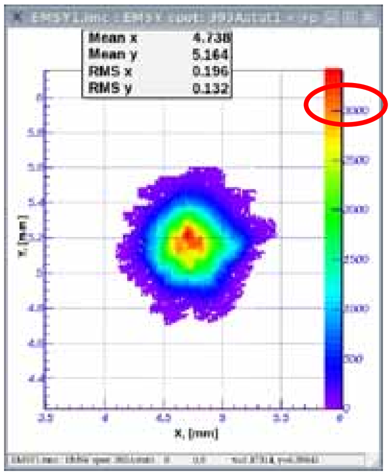
- ~2002-2003 rough divergence estimation using center beamlet, 8 bit camera
- 2003-2005 sheared emittance estimation using 3 slit positions (0; +/-0.7*sigmaX), 8-bit camera
- 2005-2008 – "manual" scan (~200um step) → phase space reconstruction, 12-bit camera
- 2009-2011 – automated synchronized slit scan with adjustable scan speed → phase space "on-line", 12-bit cameras, zoom option, scale procedure

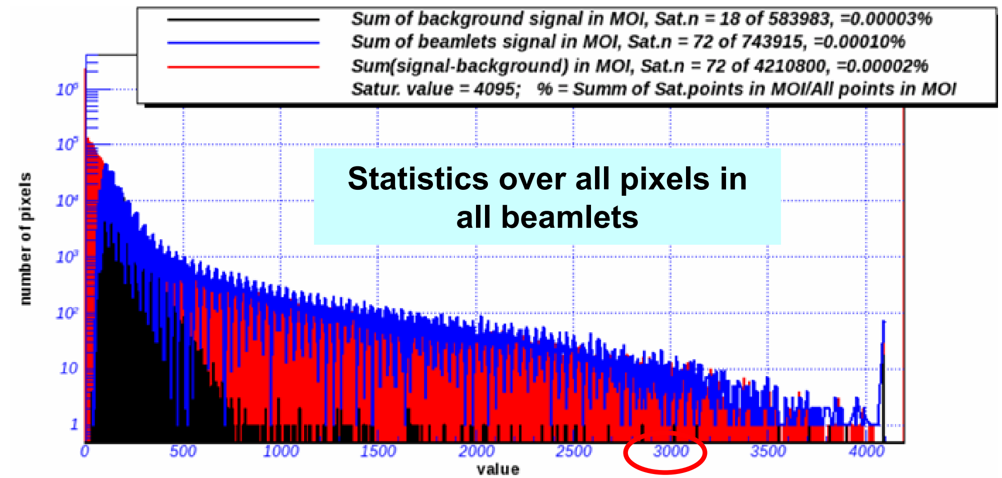
The emittance measurement procedure at PITZ:
• under permanent improvement in terms of resolution and sensitivity
• as conservative as possible **(100% rms emittance)!**
*!NB: measured emittance numbers are permanently **reducing** as a result of machine upgrades and extensive optimization*

"we are measuring more and more of less and less…"

Beam(let) image measurements

- 12-bit camera is important!
- Quality criteria: max bit ≥ 3000 (at least from $4095=2^{12}-1$ max)
  - Adjustment of the camera gain G and the number of pulses NoP in a pulse train including camera gating to use the camera dynamic range as much as possible
  - For the beamlet collection -> auxiliary histogram -> at least several bits of some beamlets with an intensity of ≥ 3000





using advantage of the long pulse operation!

- Image filtering
  - 3-sigma filter
  - Bkg-subtraction
  - X-ray filter
  - MOI=mask of interest at the beamlet collector screen

Slit scan technique at PITZ: how it works now

> Setup the machine

- laser temporal and transverse
- laser BBA at the cathode
- gun phase
- bunch charge
- booster phase and gradient – beam energy (longitudinal momentum)

> For a chosen main solenoid current (bucking in compensation)

- Beam transverse distribution (rms size) at EMSY ➔ 12-bit camera!; frames=50xSignal+50xBkg (laser shutter closed) with adjusted camera gain G and NoP
- Beam transverse distribution at beamlet collection screen for MOI ➔ 12-bit camera! frames=50xSignal+50xBkg (laser shutter closed) with adjusted camera gain G and NoP
- Slit scan (typical speed 0.1-0.5mm/sec) with simultaneous beamlet image taking. Synchronization of the slit position and the frame acquisition (10Hz!) with adjusted camera gain G and NoP
- Slit scan with closed laser shutter for the average bkg calculation

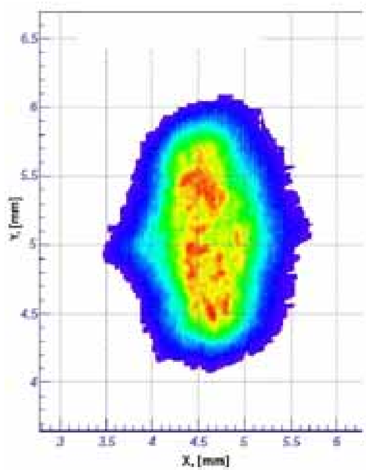
> Transverse phase space reconstruction and emittance calculations

- Phase space linear shift to take the slit position into account
- Scaling procedure (more details in the next slide)

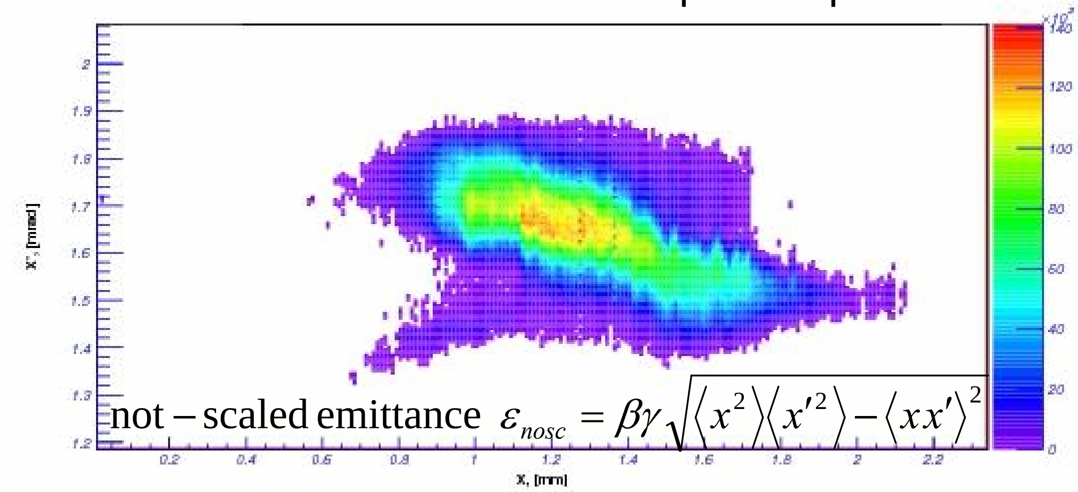
> Error analysis (systematic and statistics – e.g. 3x5)

Slit scan technique at PITZ: scale procedure

measured beam at EMSY screen



measured transverse phase space



not – scaled emittance $\varepsilon_{nosc} = \beta\gamma\sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$

X_{rms}^{EMSY} ⇐ X-projection $\neq$ X-projection ⇒ $\sigma_{x0} = \sqrt{\langle x^2\rangle}$

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scale factor $SF = \dfrac{X_{rms}^{EMSY}}{\sigma_{x0}} > 1$

scaled emittance $\varepsilon_{sc} = \varepsilon_{nosc} \cdot SF$

scale factor introduced to correct for low intensity losses from beamlet measurements

Photo injector parameters to be optimized

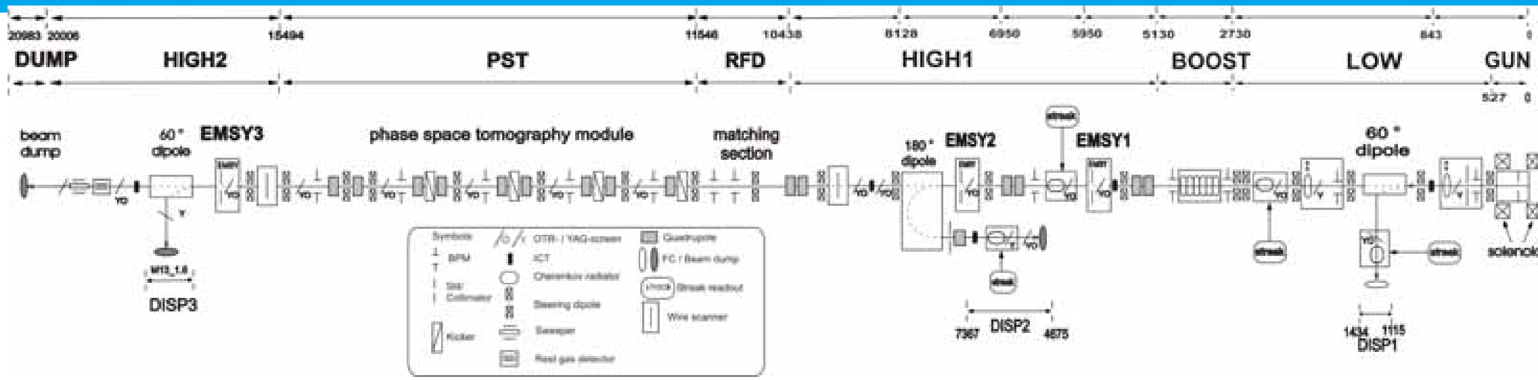


Photo injector parameters:
- **to be varied and optimized**
- **to be adjusted and controlled**

Gun:
- Ecath=60MV/m (fixed)
- **Launch rf phase ~on-crest**
- **Laser BBA**
- **RF pulse duration and FB**

Solenoid:
- **Imain = main solenoid**
- Compensating Ibuck
- **Solenoid BBA**

Booster cavity (CDS):
- Emax
- **RF phase ~on-crest**
- **RF pulse length**

Cathode laser:
- **Transverse profile and size X,Yrms**
- **Temporal profile -> ~20..22ps, short rt**
- **Pulse train length (NoP)**

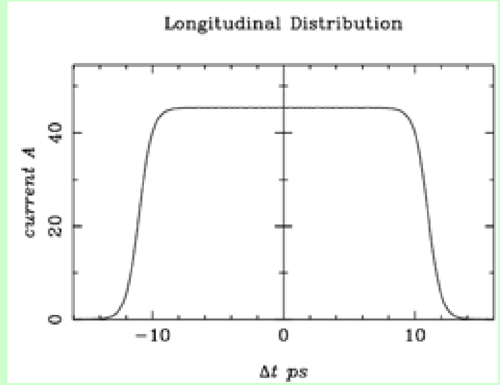
Electron bunch:
- **Charge/bunch**
- **Trajectory (e.g. bypass the vacuum mirror)**

Beam dynamics simulations for PITZ-1.8

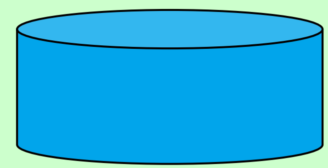
Optimized machine setup (ASTRA simulations)

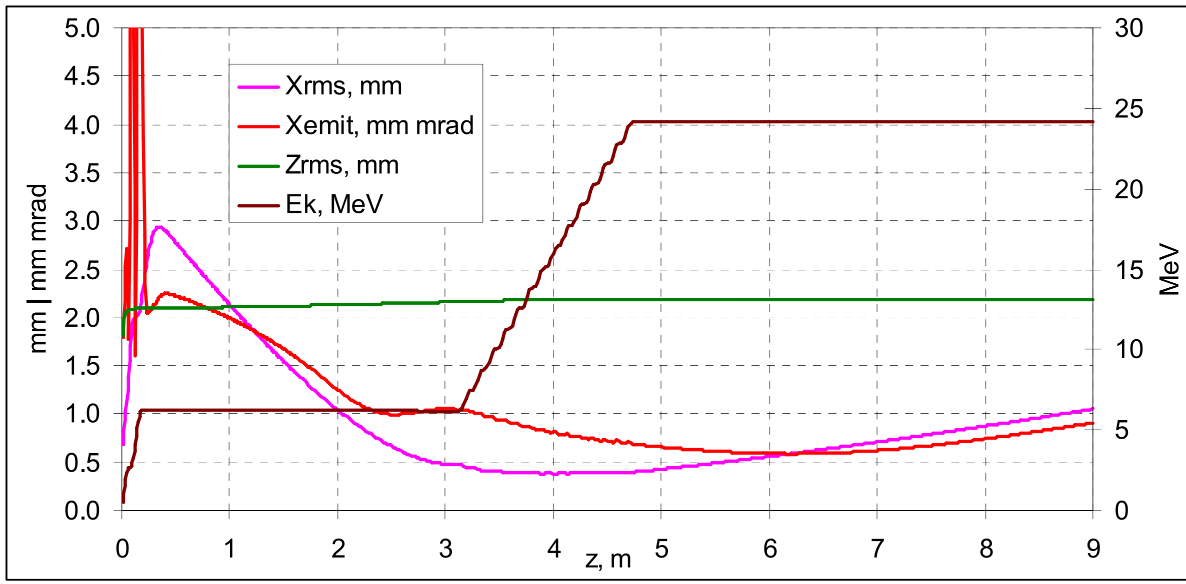
	parameter	unit	value
cathode laser	temporal	profile	flat-top
	transverse	distribution	rad.homogen
	rt/FWHM\ft	ps	2/22\2
	XYrms	mm	0.401
	Ek	eV	0.55
	th.emit.	mm mrad	0.34
RF-gun	Ecath	MV/m	60.58
	phase	deg	-1.116
	maxBz	T	-0.22808
CDS boost	maxE	MV/m	20.6
	phase	deg	0
e-beam @EMSY1	charge	nC	1
	momentum	MeV/c	24.64
	proj.emit.	mm mrad	**0.60**
	th./proj.em.	%	**57%**
	<sl.emit.>	mm mrad	0.53

Laser distributions at the cathode



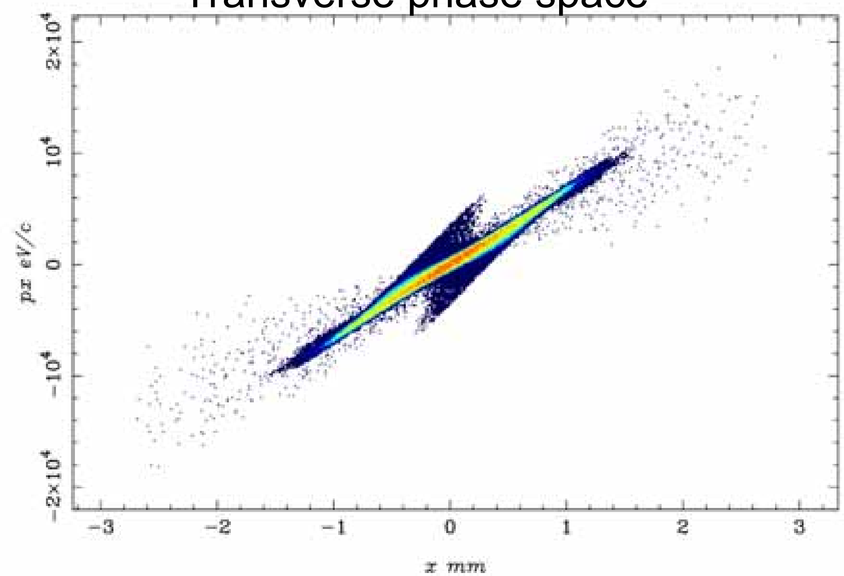
Transverse distribution
radial homogeneous



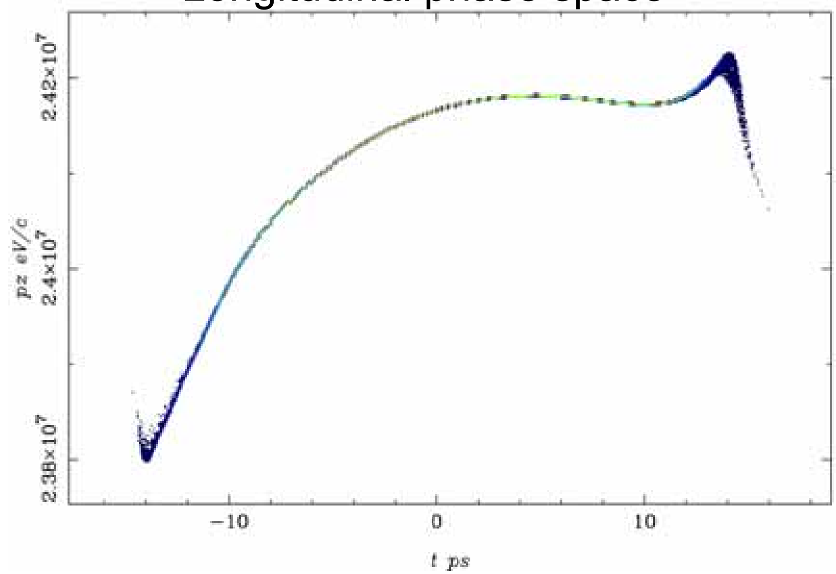


Beam dynamics simulations for PITZ-1.8: e-beam at EMSY

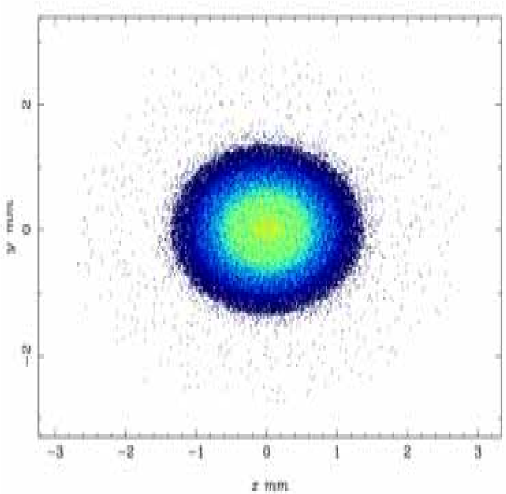
Transverse phase space



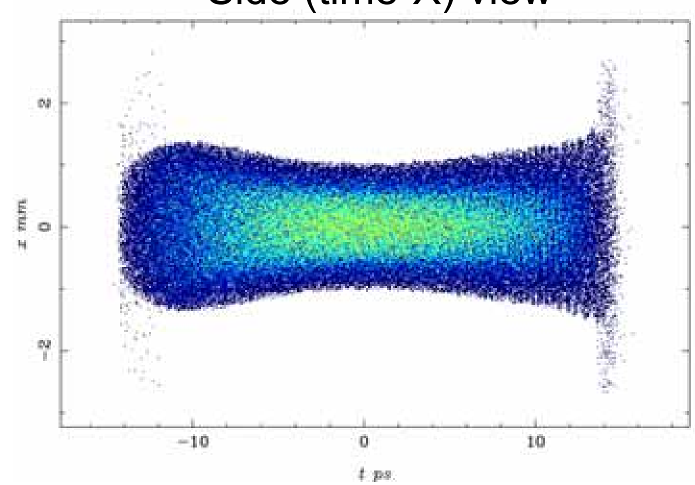
Longitudinal phase space



Transverse X-Y distribution

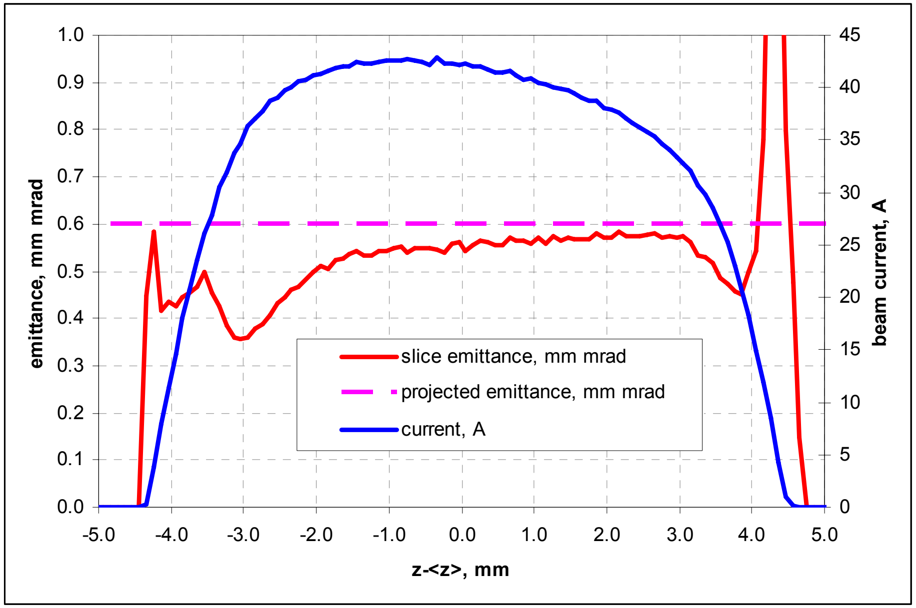


Side (time-X) view

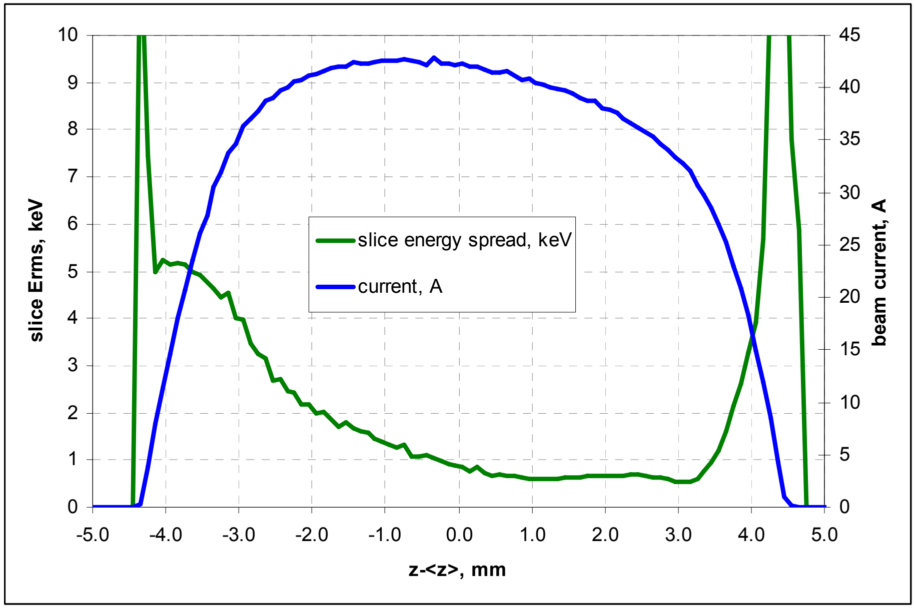


Beam dynamics simulations for PITZ-1.8: electron beam at EMSY – slice parameters

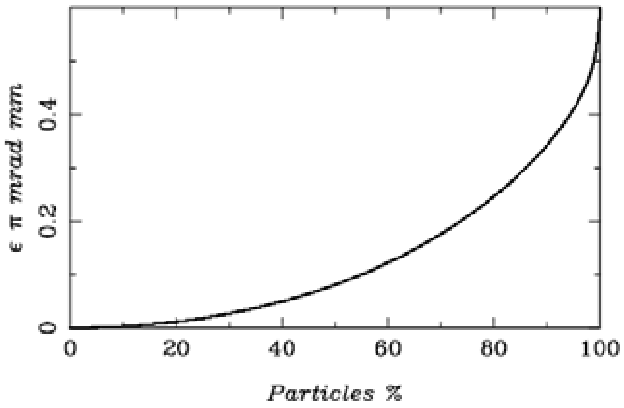
Slice emittance



Slice energy spread

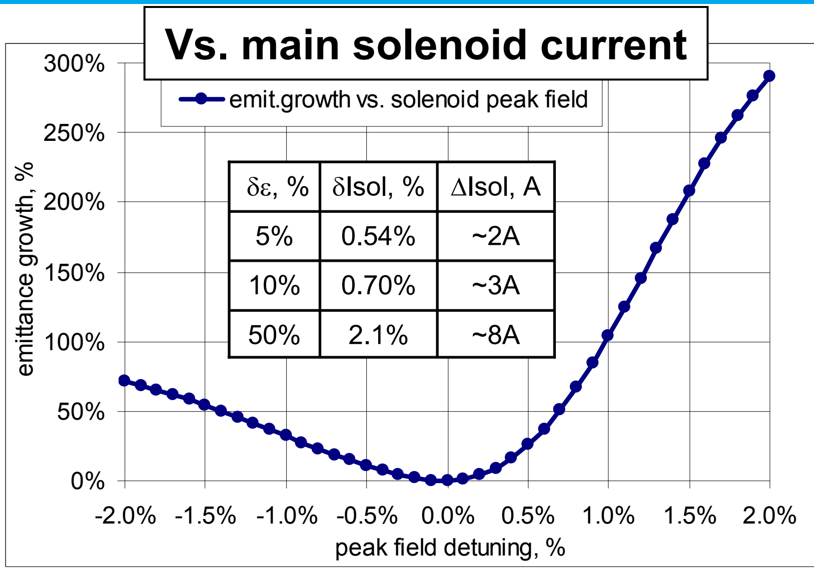


Core emittance



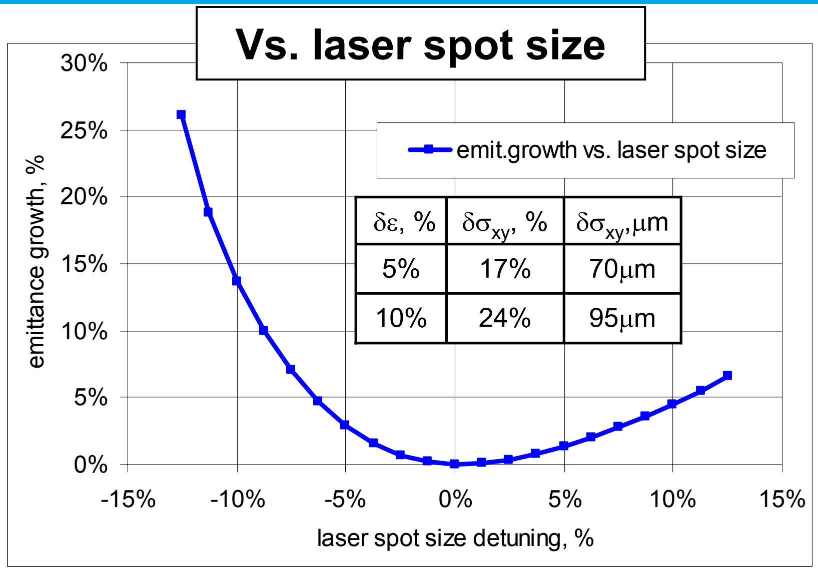
Beam dynamics simulations for PITZ-1.8: tolerances

Vs. main solenoid current



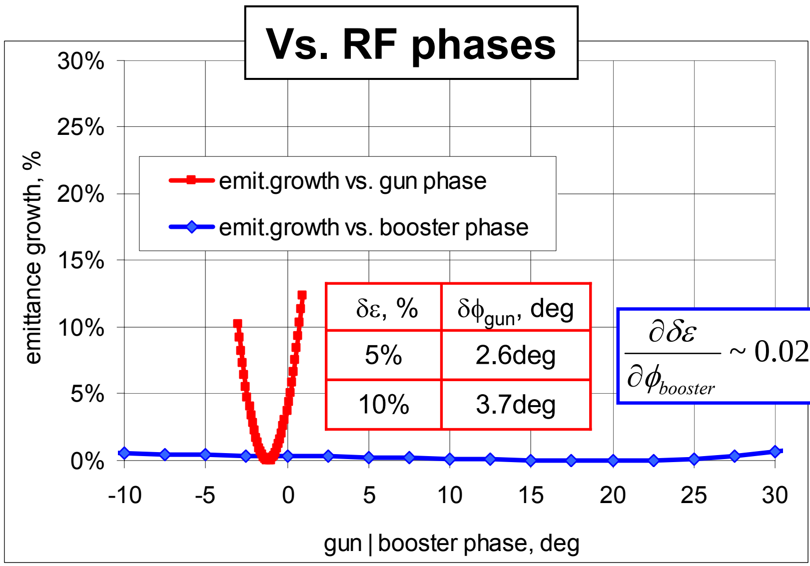
δε, %	δIsol, %	ΔIsol, A
5%	0.54%	~2A
10%	0.70%	~3A
50%	2.1%	~8A

Vs. laser spot size



δε, %	$\delta\sigma_{xy}$, %	$\delta\sigma_{xy}$, μm
5%	17%	70μm
10%	24%	95μm

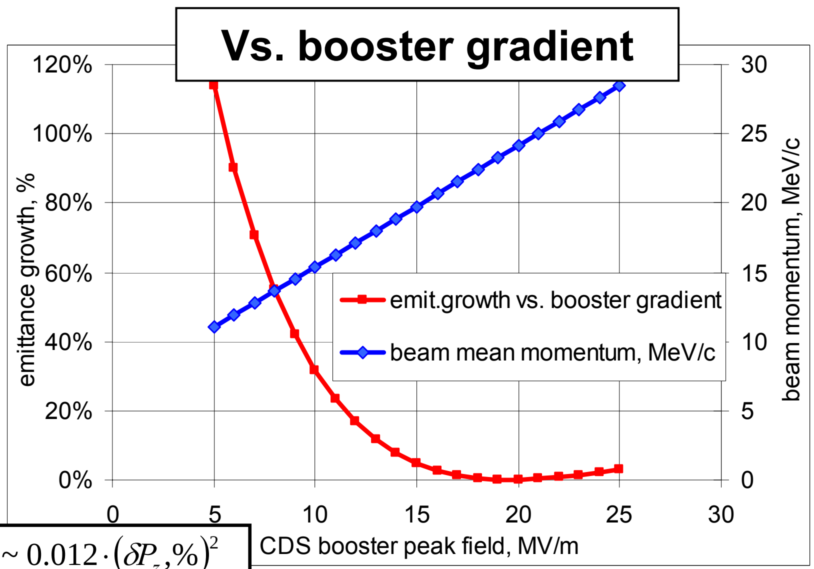
Vs. RF phases



δε, %	$\delta\phi_{gun}$, deg
5%	2.6deg
10%	3.7deg

$$\frac{\partial \delta\varepsilon}{\partial \phi_{booster}} \sim 0.02 \frac{\%}{\deg}$$

Vs. booster gradient



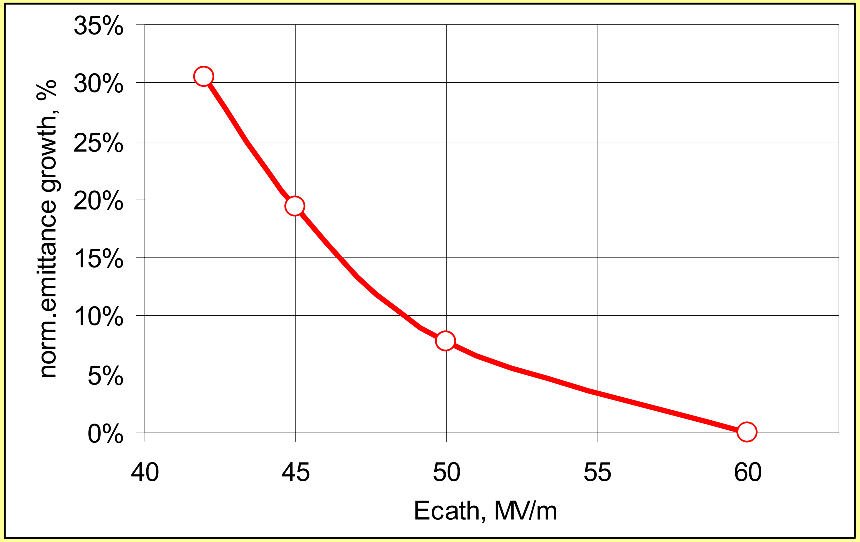
$$\delta\varepsilon,\% \sim 0.012 \cdot (\delta P_z,\%)^2$$

$$\delta\varepsilon(P_z > 18 MeV/c) < 5\%$$

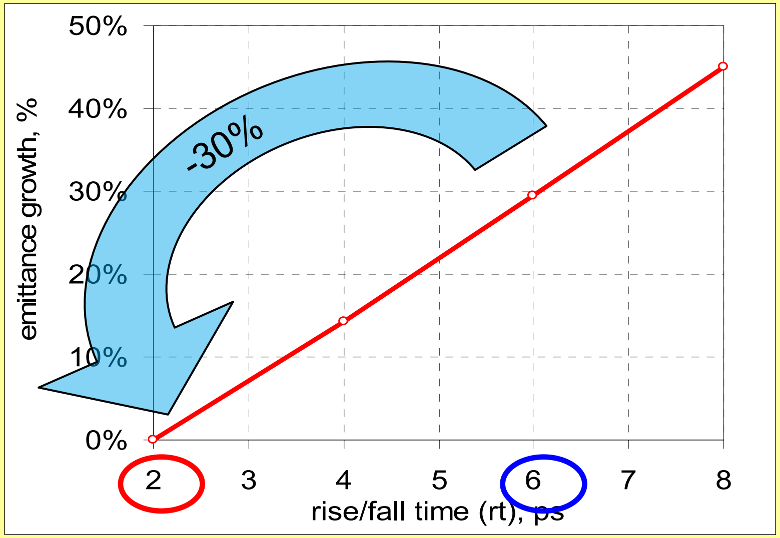
PITZ Photo Injector Test Facility Zeuthen

Beam dynamics simulations for PITZ-1.8: imperfections

Simulated emittance growth vs. gun gradient

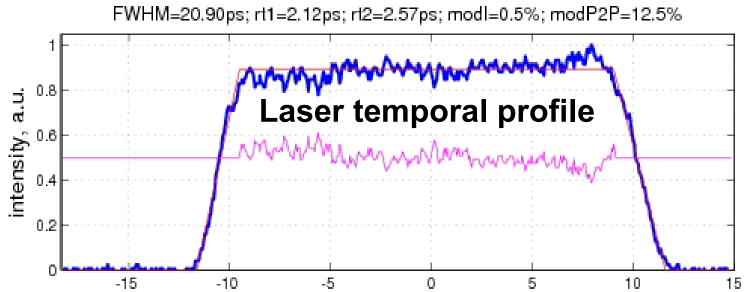


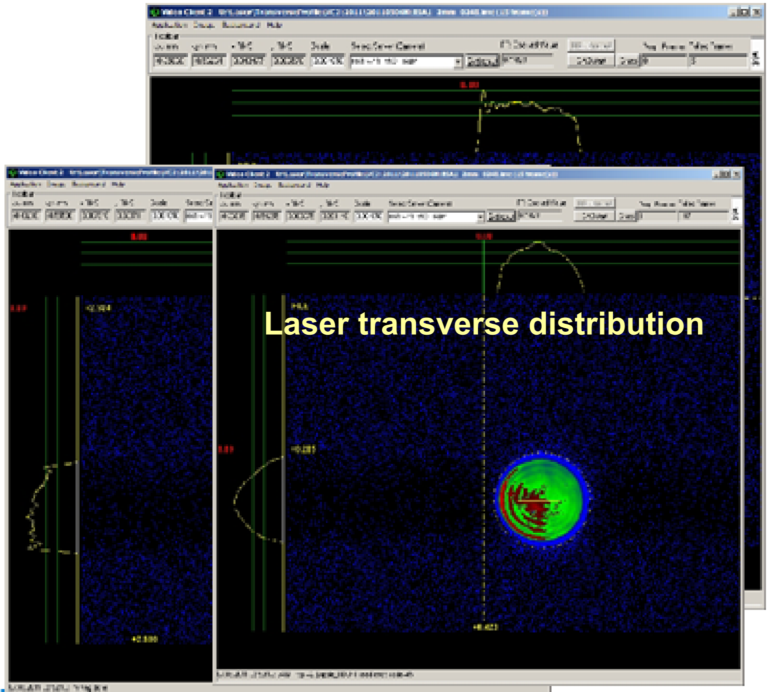
Simulated emittance growth vs. cathode laser rise/fall time

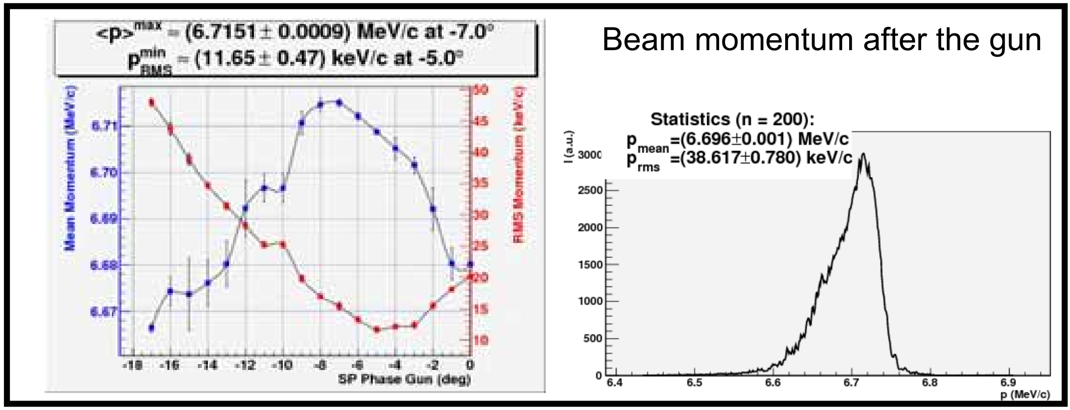


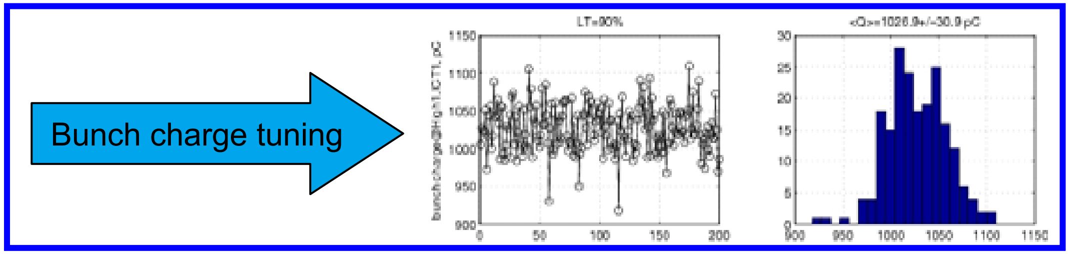
Emittance measurements at PITZ (typical solenoid scan)

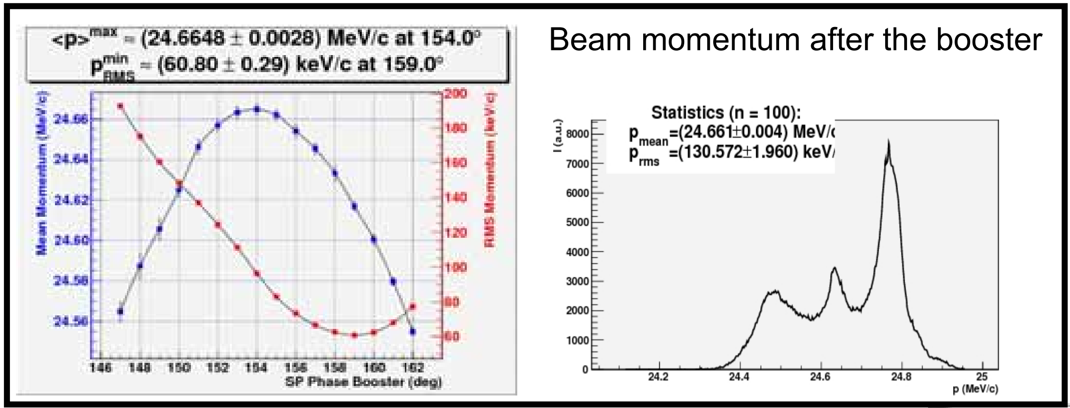
Machine setup (07.05.2011M): BSA=1.2mm; gun=6deg off crest; 1nC; booster=on-crest







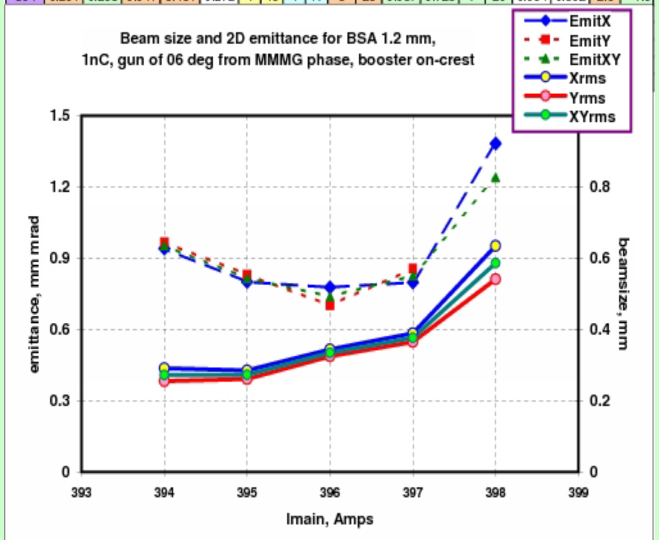




Emittance measurements at PITZ: typical solenoid scan

1) Solenoid scan for X and Y emittance

I_main (A)	Xrms, mm	Yrms, mm	EmitX_2D, mm mrad	EmitX_2D, nonscaled	XYrms, mm	EMSY1 NoP	EMSY1 Gain	MOI NoP	MOI, Gain	XBL NoP	XBL gain	EmitY_2D, mm mrad	EmitY_2D, nonscaled	YBL NoP	YBL gain	EmitXY_2D, mm.mrad	EmitXY_2D, nonscaled	X-scale factor	Y-scale factor
For all measurements f250 lenses and 2x2 binning were used																			
398	0.635	0.541	1.383	0.905	0.586	3	20	2	20	26	20	1.113	1.049	25	20	1.241	0.974	1.5	1.3
397	0.389	0.365	0.798	0.632	0.377	1	24	1	23	14	20	0.856	0.798	13	20	0.826	0.710	1.3	1.2
396	0.344	0.325	0.778	0.514	0.334	1	21	1	21	7	20	0.701	0.606	8	20	0.738	0.558	1.5	1.3
395	0.285	0.261	0.800	0.477	0.273	1	17	1	18	5	20	0.831	0.732	7	20	0.815	0.591	1.7	1.4
394	0.291	0.255	0.941	0.481	0.272	1	15	1	17	5	20	0.967	0.728	7	20	0.954	0.592	2.0	1.6



07.05.2011M: sol.scan:
Xemit | Yemit | XYemit
0.778 | 0.701 | 0.738

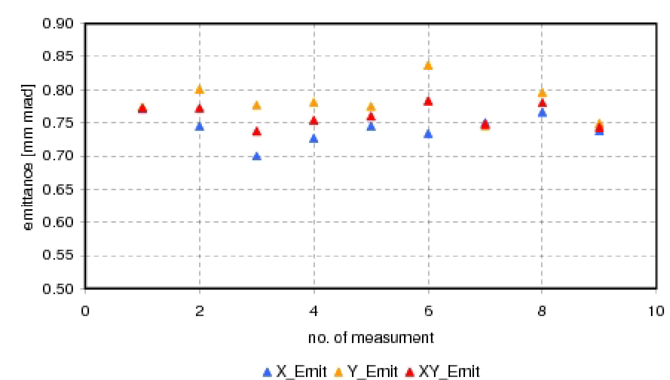
2) 3x3 statistics for the bes solenoid current

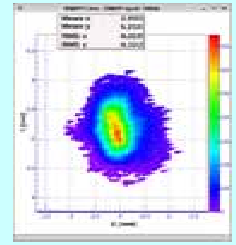
Solenoid 396 A

EMSY1 NoP	1	1	1
EMSY1 Gain	21	21	21
MOI NoP	1	1	1
MOI Gain	20	20	20
XBL NoP	6	7	6
XBL Gain	20	20	20
YBL NoP	8	10	9
YBL Gain	20	20	20

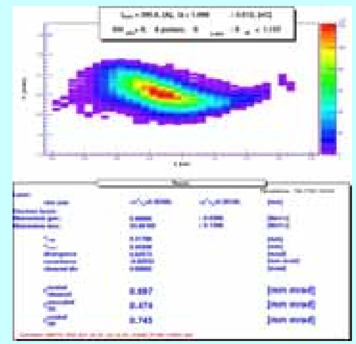
3x3 measurements

meas	beam size @ EMSY			X-emittance		Y-emittance		XYemit, scaled	XYemit, nonscaled
	X	Y	XY	scaled	nonscaled	scaled	nonscaled		
1	0.318	0.322	0.320	0.771	0.492	0.774	0.691	0.772	0.583
2	0.318	0.322	0.320	0.745	0.474	0.801	0.700	0.772	0.576
3	0.318	0.322	0.320	0.700	0.471	0.777	0.669	0.737	0.561
4	0.316	0.314	0.315	0.727	0.497	0.781	0.730	0.754	0.602
5	0.316	0.314	0.315	0.745	0.498	0.775	0.763	0.760	0.616
6	0.316	0.314	0.315	0.734	0.516	0.837	0.770	0.784	0.630
7	0.309	0.313	0.311	0.750	0.513	0.746	0.666	0.748	0.585
8	0.309	0.313	0.311	0.766	0.531	0.796	0.709	0.781	0.614
9	0.309	0.313	0.311	0.738	0.500	0.749	0.691	0.743	0.588
Mean	0.314	0.316	0.315	0.742	0.499	0.782	0.710	0.761	0.595
Std	0.004	0.004	0.004	0.021	0.019	0.028	0.037	0.017	0.022

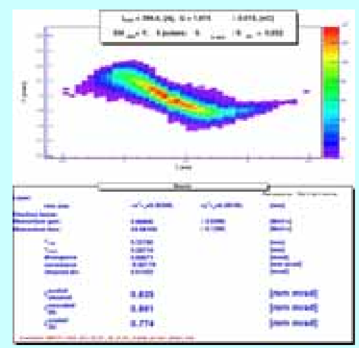




beam at EMSY: 3x1



XPx: 3x3



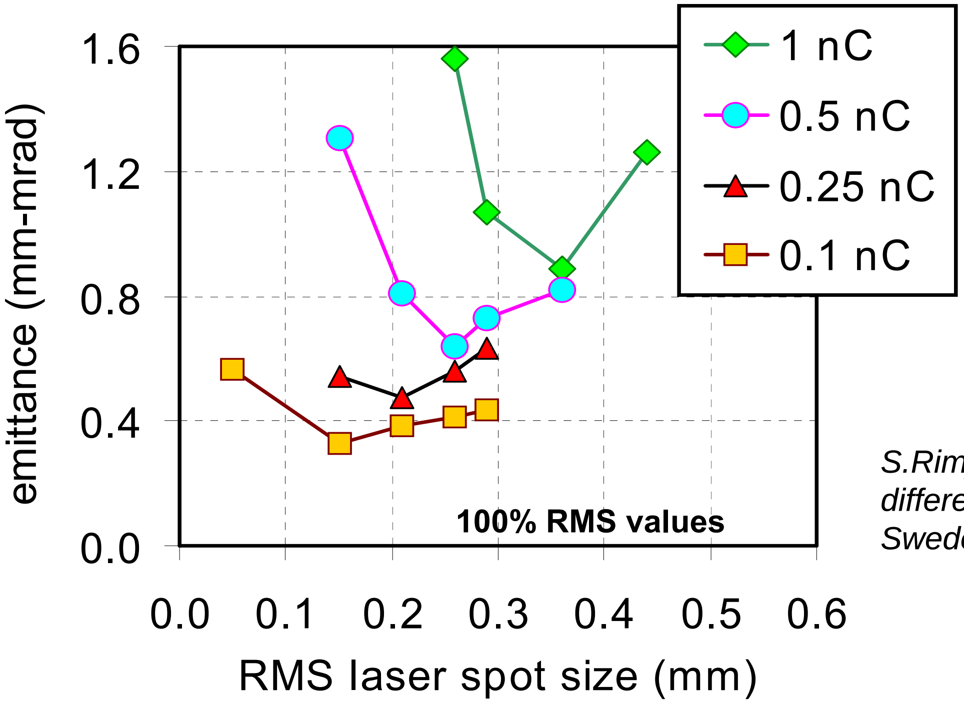
YPy: 3x3

07.05.2011M: 3x3 stat:
Xemit=(0.742±0.021stat) mm mrad
Yemit=(0.782 ±0.028stat)mm mrad
XYemit=(0.761± 0.017stat)mm mrad

Geometrical averaged emittance: $\varepsilon_{xy} = \sqrt{\varepsilon_x \varepsilon_y}$

Emittance for different charges for PITZ1.7 setup (2009)

- **Laser temporal profile:** flat-top, 23-25 ps (FWHM), 2-3 ps rise-time, 3-4 ps fall-time
- **Laser (rms) spot size:** 0.05 → 0.44 mm
- **Maximum gun momentum:** ~6.68 MeV/c
- **Gun phase:** +6 deg from maximum mean momentum gain phase
- **Booster phase**: max. momentum gain phase → ~14.5 MeV/c for 1 nC bunch charge
  → ~12.3 MeV/c beam momentum for lower changes



Measurements 2009				
Q (nC)	**1**	**0.5**	**0.25**	**0.1**
σ_{xy} (mm)	0.36	0.26	0.21	0.15
ε_x	0.72±0.01	0.53	0.42	0.29
ε_y	1.09±0.02	0.77	0.53	0.37
ε_{xy}	0.89±0.01	0.64	0.47	0.33

S.Rimjaem et al."Measurements of transverse projected emittance for different bunch charges at PITZ", Proceedings of FEL2010, Malmö, Sweden, pp.410-413.

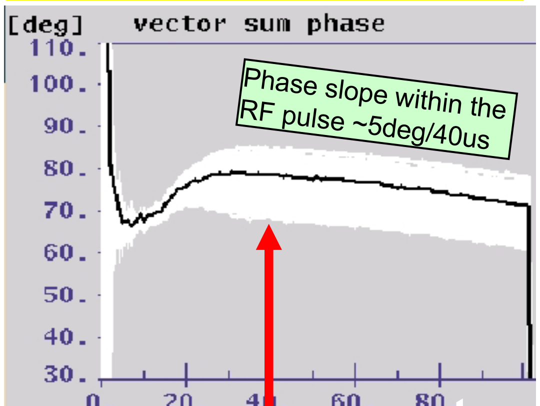
these results + experience from LCLS (only small degradation of slice emittance from gun to undulator) ➔**FEL can be operated with 14 GeV beam energy**

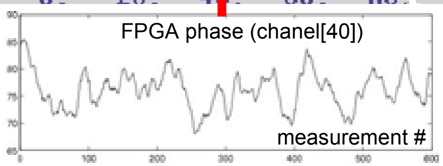
•**Gun now in operation at FLASH**
•But! Increase of measured emittance values due to phase jitter and slope over train! (especially for low charges)

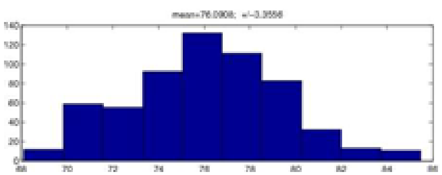
Improvement of the RF gun phase stability

2009 (no FB)

FPGA phase, reconstructed from virtual ADC probes based on 2x5MW directional couplers

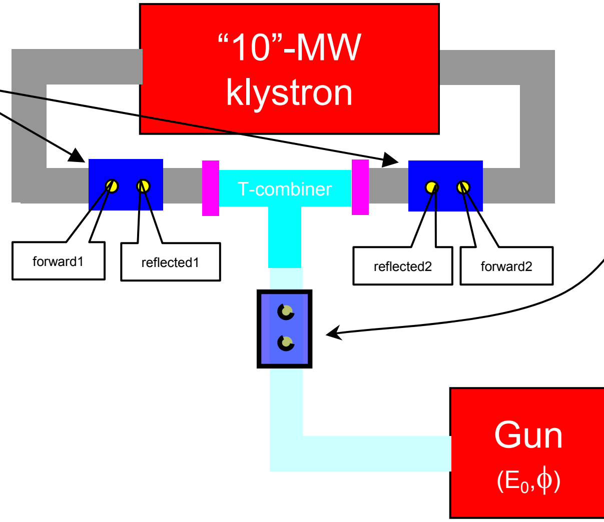






Phase fluctuations:

- **10..15 deg (p-p)**
- 2..4 deg (rms)

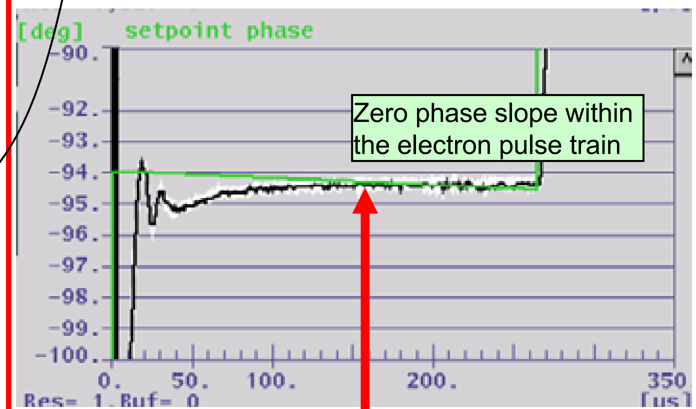


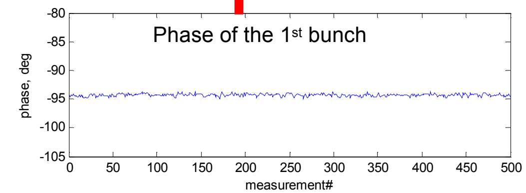
10-MW in-vacuum directional coupler installed since 2010

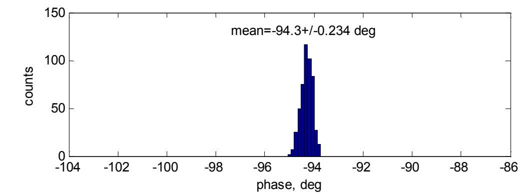
Manufacturer: Mega Industries, USA

2011 (FB is ON!)

FPGA phase, measured by 10MW in-vacuum directional coupler



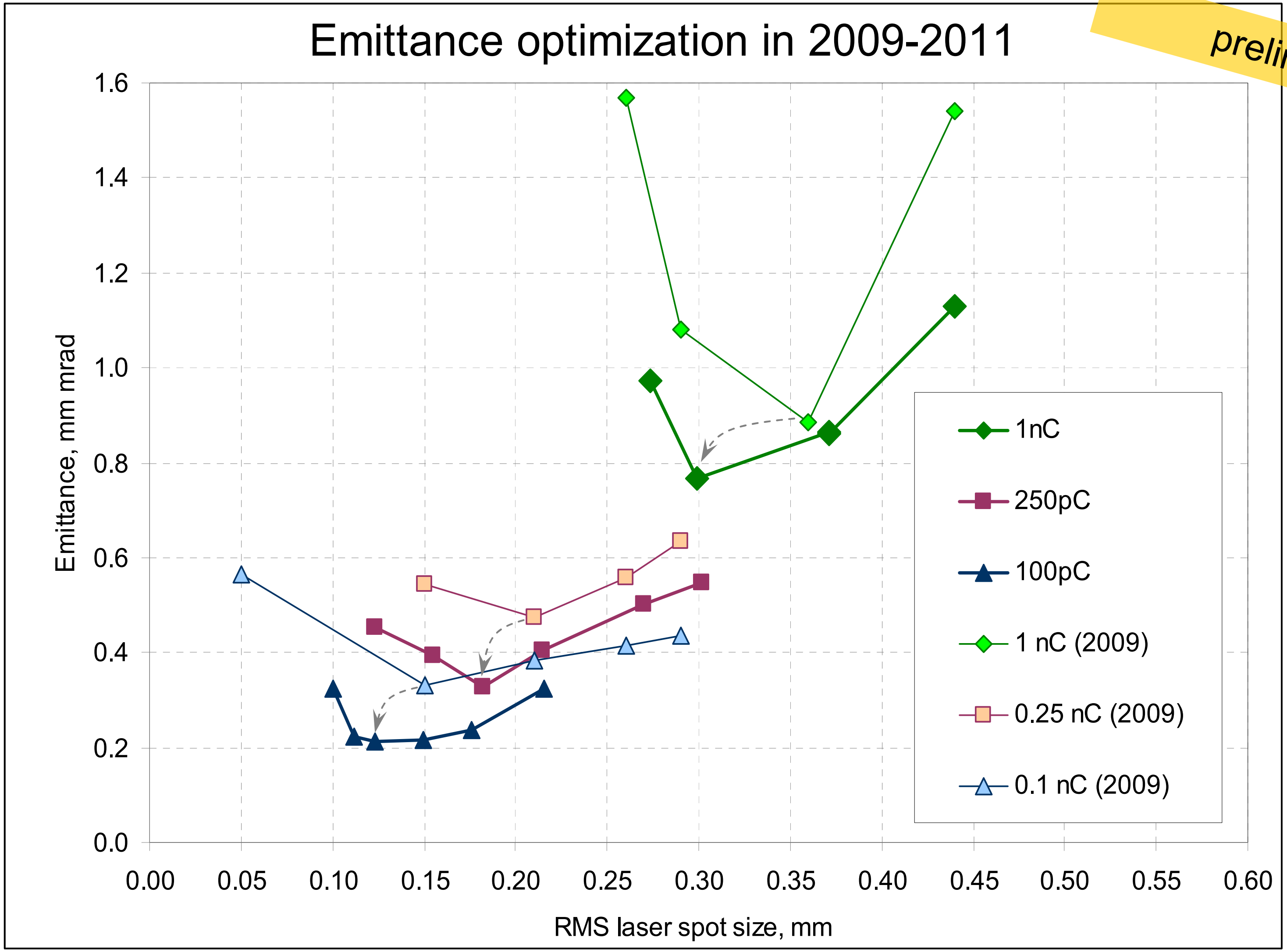




Phase fluctuations:

- **1..1.5 deg (p-p)**
- 0.2..0.3 deg (rms)

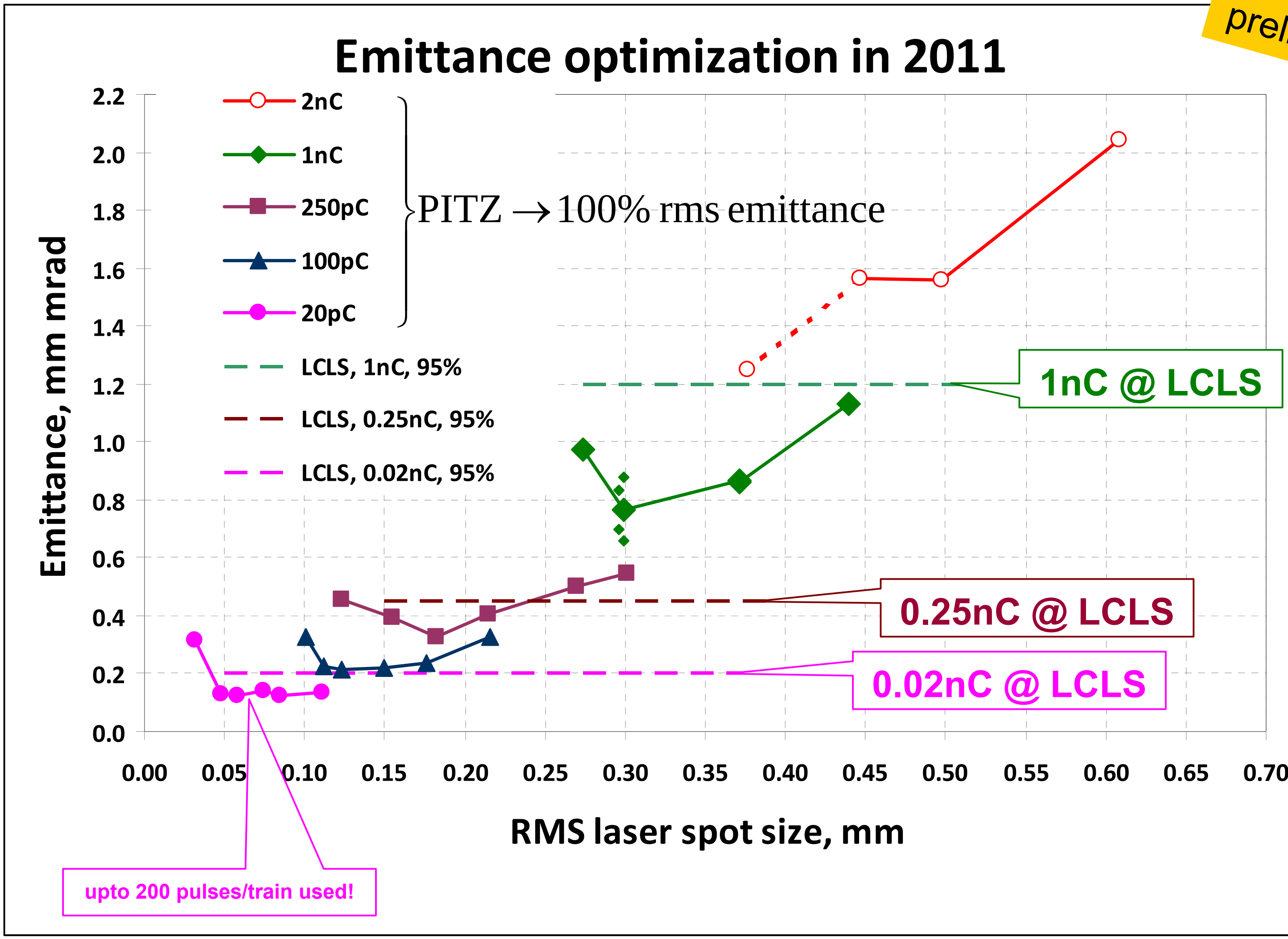
Projected emittance measurements at PITZ 2009-2011



- >beam energy increased to ~25MeV (2009:<15MeV)
- >slightly different transverse laser shape
- >**SIGNIFICANTLY improved RF phase stability !!**

Projected emittance measurements at PITZ 2011

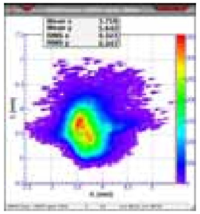
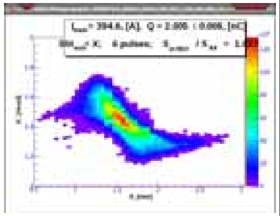
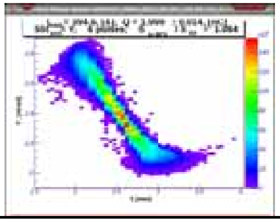
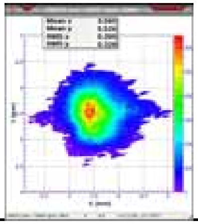
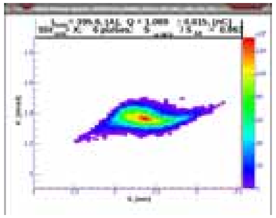
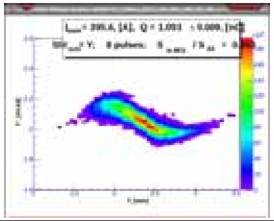
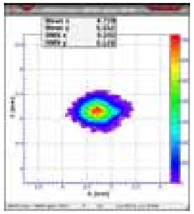
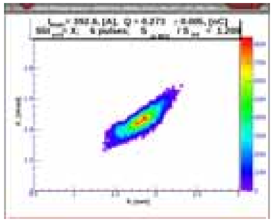
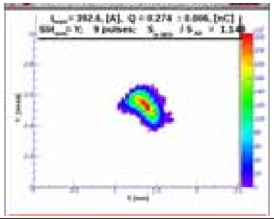
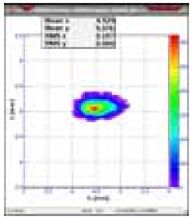
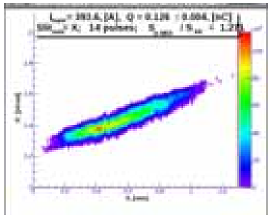
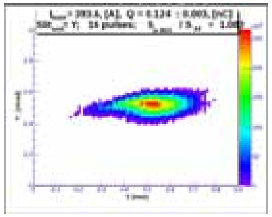
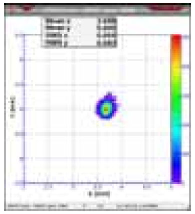
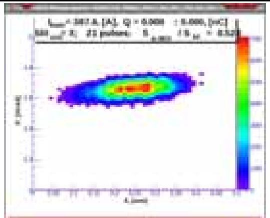
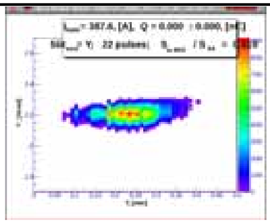
preliminary



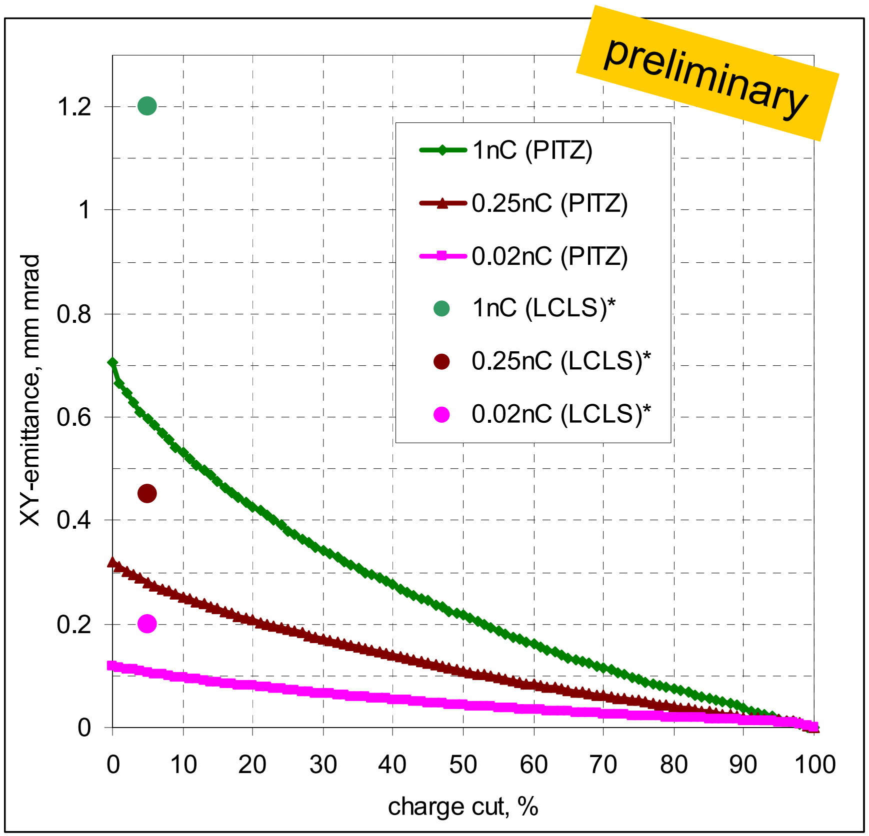
PITZ is setting a new benchmark for minimum emittance at a given charge
+
capable of operation at high duty cycle!!

Projected emittance measurements at PITZ 2011

preliminary

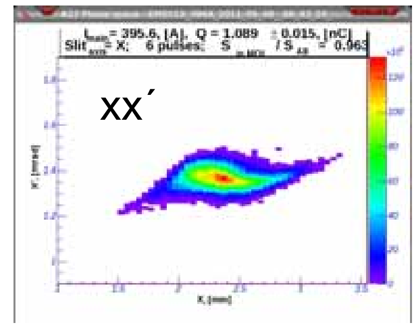
Q, nC	shift statistics	laser BSA / σ_{xy} mm	ϕ_{gun} / $\phi_{booster}$, deg	Pz(after gun) / Pz(final), MeV/c	Beam at EMSY1	X-phase space	Y-phase space	Xemit Yemit XYemit, mm mrad	Remark
2.0	03.05.20 11M-A 3x3 stat	1.5 / 0.377	6 / 0	6.69 / 24.79				1.239 1.267 1.251	
1.0	07.05.20 11N 3x3 stat	1.2 / 0.300	6 / 0	6.67 / 24.67				0.724 0.603 0.661	Same scale span for phase spaces
0.25	06.04.20 11N 3x5 stat	0.7 / 0.182	0 / 0	6.70 / 25.07				0.367 0.292 0.328	
0.1	12.04.20 11M 3x3 stat	0.5 / 0.123	0 / 0	6.71 / 24.91				0.281 0.160 0.212	
0.02	30.04.20 11A 2x3+4stat	0.35 / 0.085	0 / 0	6.76 / 23.68				0.111 0.133 0.121	Zoomed phase spaces

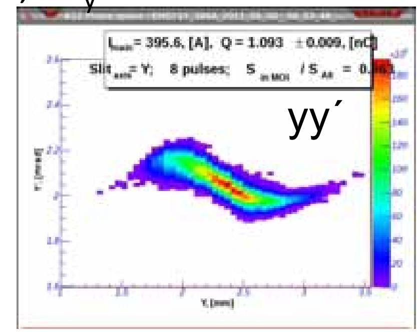
Emittance measurements at PITZ 2011: core emittance



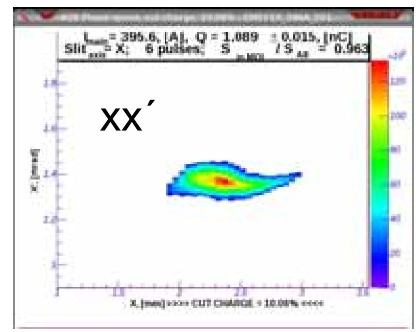
*LCLS results: projected emittance, 95% RMS values.
D. Dowell + P. Emma, priv. commun. + FEL2009

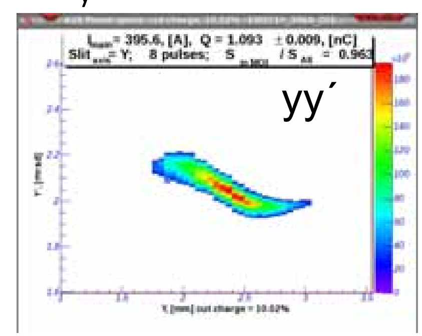
100% of 1nC: ε_x = 0.77 mm mrad, ε_y = 0.65 mm mrad





90% of 1nC: ε_x = 0.58 mm mrad, ε_y = 0.49 mm mrad

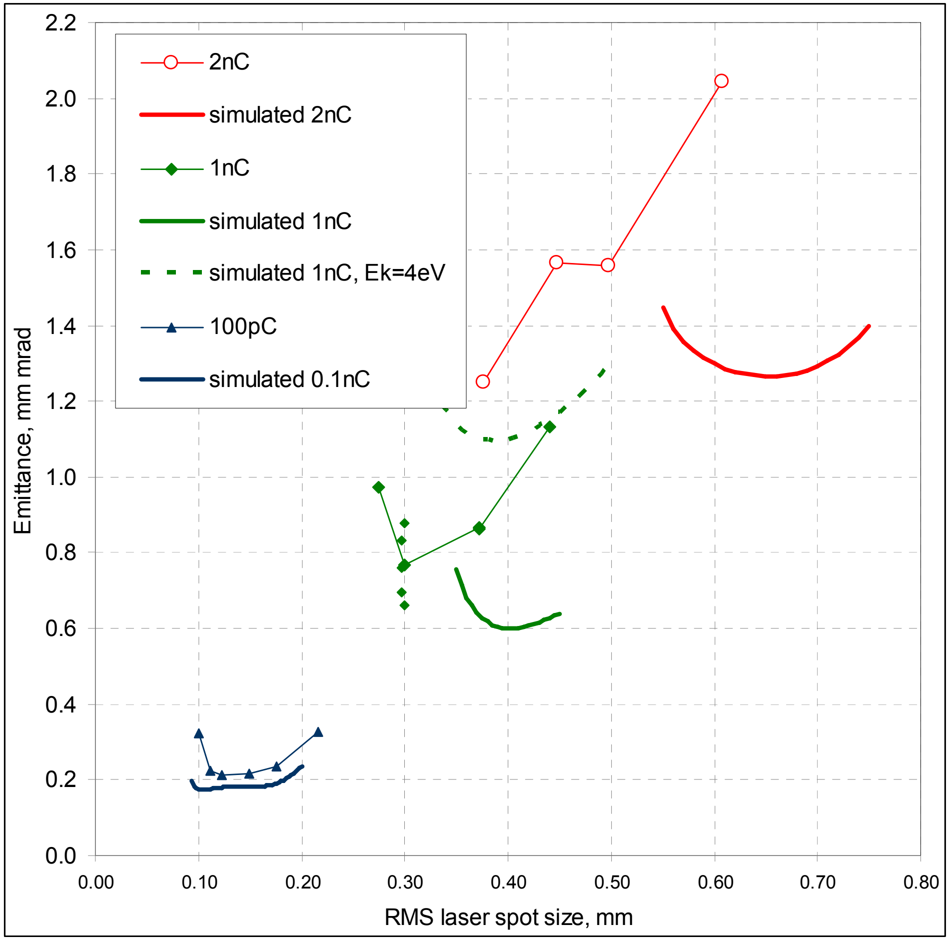




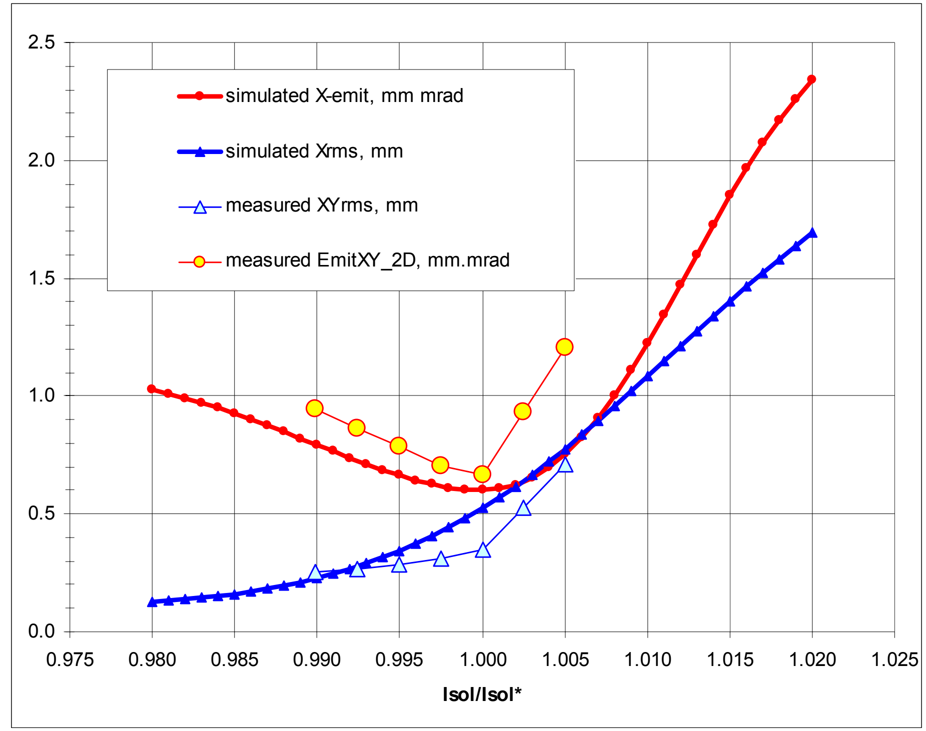
	LCLS (95% RMS values)*		**PITZ (100% RMS)**	**PITZ (95% RMS)**
Q, nC	projected ε	slice ε	**projected ε**	**projected ε**
1	1.2	0.9	**0.71**	**0.60**
0.25	0.45	0.4	**0.32**	**0.28**
0.02	0.2	0.14	**0.12**	**0.11**

Emittance at PITZ: measurements vs simulations

Various bunch charges



Solenoid scan for 1nC



Optimum simulations vs. optimum measurements, but different laser rms spot size!!

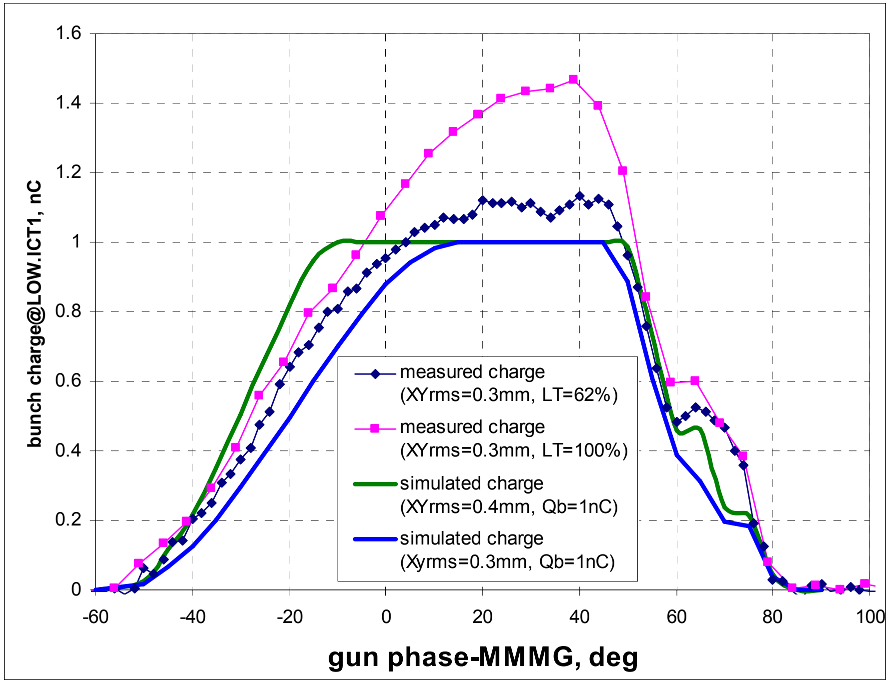
Only for 0.1nC rather good agreement on an optimum rms laser spot size!

Experimental optimization is very important !

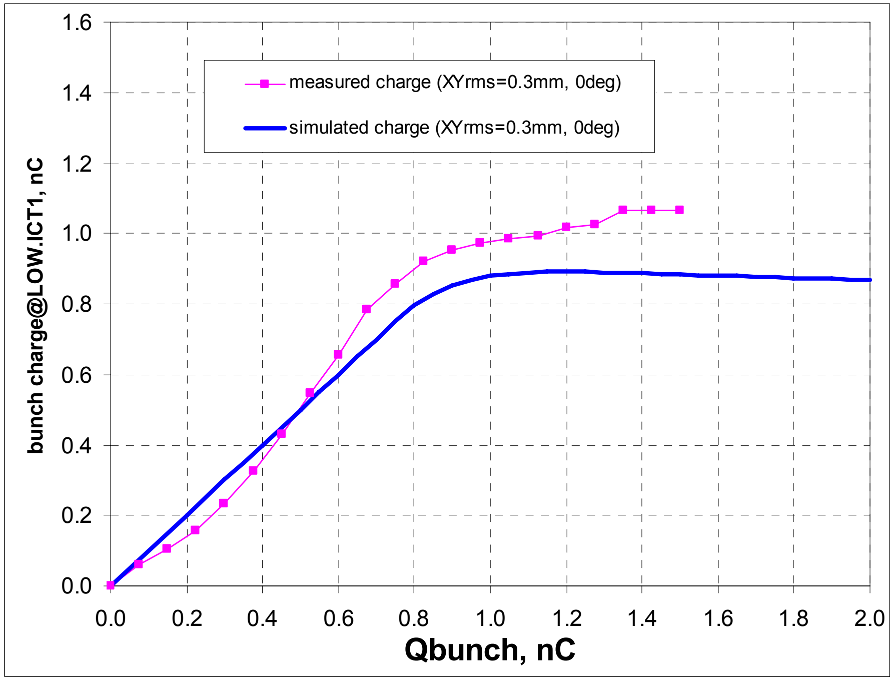
Emittance at PITZ: measurements vs simulations

Reasons of the discrepancy? ➔ **emission**

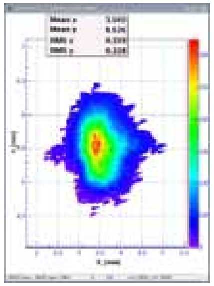
Measured and simulated Schottky scans



Measured and simulated laser energy scan



ASTRA: Qbunch → initial bunch charge at the cathode
Measurement: → a*LT~laser energy



?Electron beam x-y asymmetry -> scale factor SF_x upto 2..3

Rough schedule for the future

PITZ delivered decisive contributions to FLASH and XFEL and can also be a **goldmine** in future:

Timeline:

- Jun.`11-Nov.`11: Shutdown for installing TDS, HEDA2 and Toshiba klystron
- Dec.`11-Jun.`12: **Run**
- **July`12**: start to install and condition general purpose **XFEL-FLASH-PITZ-Gun**

Scientifics:

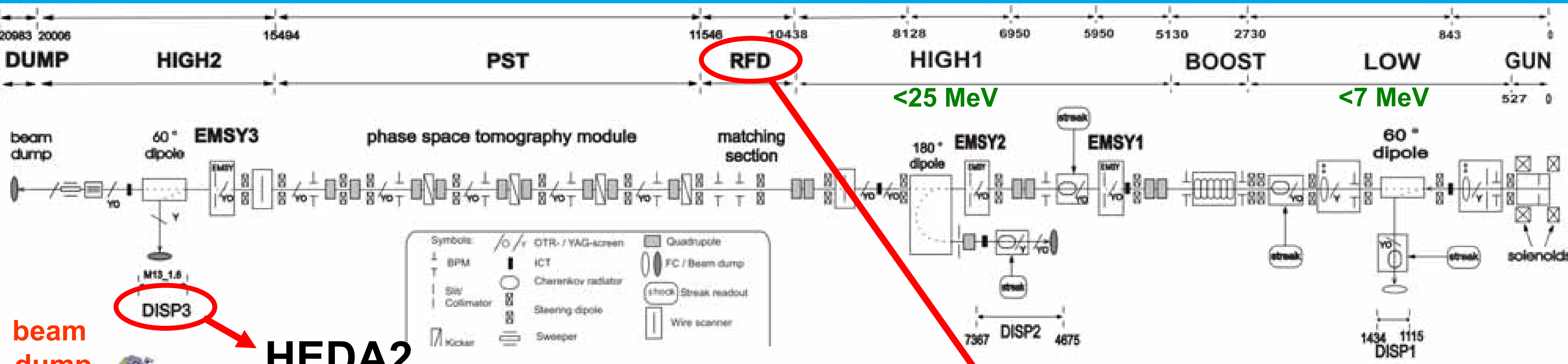
Bread & Butter (ongoing, partially done) **:**

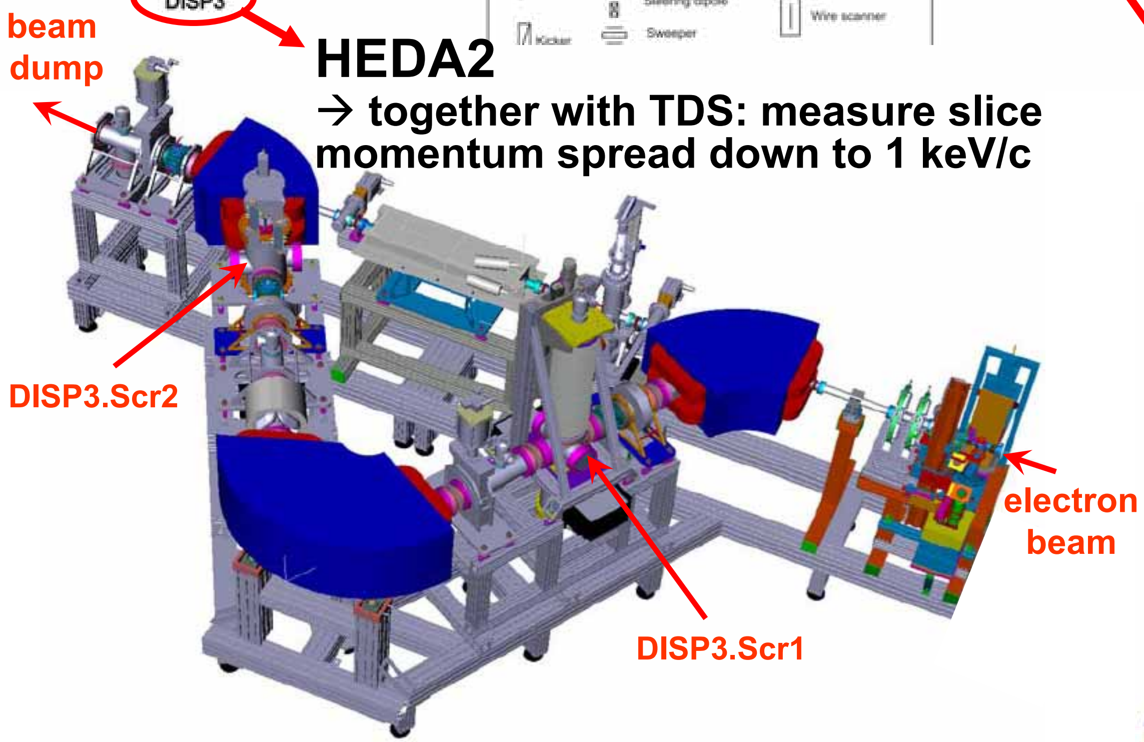
- Characterizing XFEL gun, later higher rep.rate
- XFEL test bed, e.g. laser system (4.5MHz + therm. lens), beam diagnostics

New tasks/options (honey from low emittance, high duty cycle, flexibility @PITZ) **:**

- Optimizing new operation modes: **ultra short bunches** (single spike lasing)
  → together with HH: S2E simulations, exp. tests, diagnostics
  → **3D elliptical laser pulses** on cathode: lower **ε,** halo, bunch length
- E.g. participation in **Plasma Acceleration**

PITZ setup: now and upgrades during this year



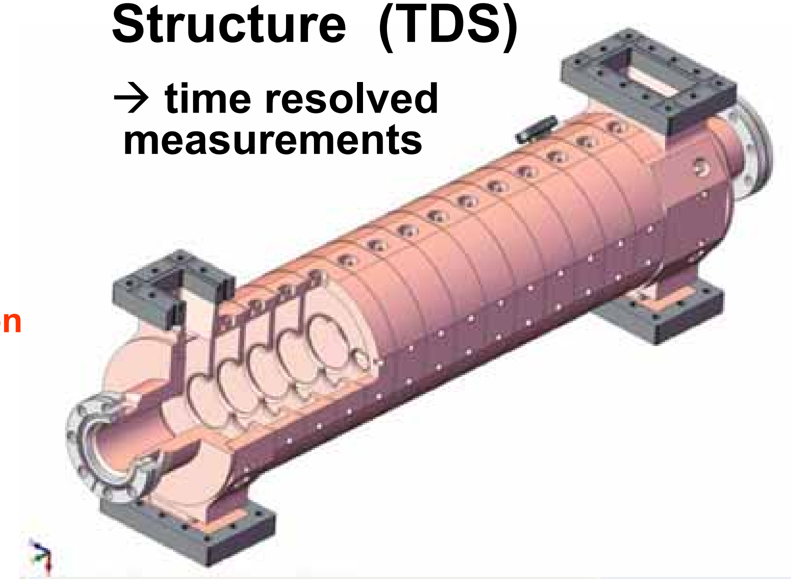


HEDA2

→ together with TDS: measure slice momentum spread down to 1 keV/c

Transverse Deflecting Structure (TDS)

→ time resolved measurements



Summary

> PITZ = benchmark for high brightness electron sources:
  - specs for the European XFEL have been demonstrated (emittance <0.9 mm mrad at 1nC)
  - beam emittance has also been optimized for a wide range of bunch charge (20pc…2nC)
  - rather high duty factor (average power, long pulse trains) in a stable operation

> The main focus at PITZ → small emittance electron beams. To reach this:
  - high gun gradients
  - laser temporal shaping
  - machine stability
  - extensive machine optimization

> Emittance measurement procedure
  - nominal method → single slit scan
  - as conservative as possible → 100% rms emittance
  - continuous improvement of the procedure

> PITZ serves also as a benchmark for theoretical understanding of the photo injector physics (beam dynamics simulations vs. measurements)

The End